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THESIS

COMPARISON OF THE RESPONSE OF SHAPE
MEMORY ALLOY ACTUATORS USING AIR-COOLING
AND WATER-COOLING

by

Robert E. Watson

December 1984

Thesis Advisor:

W. G. Culbreth

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Comparison of the Response of Shape
Memory Alloy Actuators Using Air-Cooling
and Water-Cooling

by

Robert E. Watson
Lieutenant, United States Navy
B.S., St. Lawrence University, 1977

Submitted in partial fulfillment of the
requirements for the degree of

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December 1984

ABSTRACT

Titanium-Nickel (Ti-Ni) alloy specimens with induced shape memory were subjected to various single step current inputs under water-cooled, natural convective air-cooling, and stagnant air-cooling conditions to determine cooling time constants and subsequent delay time for successive actuation. Power input, specimen recovery and reextension displacement with various loads applied to the coil shaped actuator, and temperature distributions along the coil were recorded as functions of time. Results suggested that liquid cooling was a viable method for increased actuator response time. A brief review of the phase transformations that give rise to the shape memory effect is included. Recommendations for continued research and application are discussed.

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I. INTRODUCTION

A new group of actuators, or force-motion transducers, is being developed through use of alloys which exhibit shape memory behavior. The shape memory effect occurs when a part made from an alloy is deformed at one temperature and recovers its original shape when heated to a second temperature. This effect is shown in Figure 1. Numerous applications for these thermo-mechanical actuators exist; however, one area in which shape memory alloys, or SMA's, can assert a tremendous influence is robotics. Low weight and small size actuators are prime candidates to replace stepper motors and other hydraulic or mechanical actuating systems. Recent work by the Mechanical Engineering Research Lab of Hitachi, Ltd. of Japan illustrates the extent to which SMA can be employed to reduce volume and weight of small load robotic systems [1]. Their three finger 'hand' and its 'forearm' have a mass of only 4.5 kg and the entire system is only 700 mm in total length. The forearm containing the SMA actuators is only 400 mm long, 80 mm wide, and 50 mm high. The robot can manipulate a 2.5 kg load with nearly the dexterity of a human hand.

The present work involved the design and construction of a liquid-cooling SMA testing system. A subsequent experimental investigation of SMA response time was conducted

using heated water to assist actuation and using water cooling to decrease actuator cycle time. The system was automated by using computer control of the SMA actuator and computer-aided data acquisition from the testing system.

An understanding of the basic mechanism of shape memory behavior has been included to introduce some of the working parameters used in the study of shape memory alloys.

II. MATERIALS ASPECTS OF SHAPE MEMORY ALLOYS

The shape memory effect is a behavior exhibited predominantly by titanium-nickel, copper-aluminum-nickel, and copper-zinc-aluminum alloys. Characteristic shape memory behavior occurs when an alloy is deformed from its original shape well beyond normal plastic deformation and then regains that original shape when moderately heated. Shape memory is the result of a reversible transformation, called a thermoelastic martensitic transformation, in which martensite plates form and grow continuously during cooling and then shrink by the reverse path to the parent phase of the alloy as the temperature is raised [2].

Figure 2 depicts shape memory behavior in a coiled wire and the temperature and phase transformations that the alloy undergoes during memory inducement and cycling. An alloy specimen, the coil, is prepared by annealing it at a high temperature while it is constrained in the desired shape. Rapid cooling to below the martensite finish temperature, M_f , will produce a coil of SMA in its martensitic phase. If the coil is mechanically deformed it will be able to recover that induced shape by heating it through the parent start P_s , to parent finish, P_f , temperature range.

The original shape can be recovered because internal deformations that occurred during straining will retreat along the same path by which they were introduced as the alloy is heated.

As the coil is stretched both temperature and stress will cause transformation to the SMA martensitic phase. If the coil is in the temperature range between M_d , the highest temperature at which martensite can be produced, and M_s , the martensite start temperature, stress will induce the martensitic phase. If the coil is cooled to the M_s to M_f temperature range, or below, the parent phase will transform spontaneously to martensite [2].

Only low levels of elastic strain are created during the structural change so that the elastic limits of the parent and martensite phases are not exceeded. Irreversible plastic deformations do not occur during deformation. Rather, deformation causes shear transformation of parent phase regions to stress-induced martensite. Growth and/or shrinkage of neighboring plates is such that they accommodate the small strains that do develop, and in these groups the net shape change is small [2]. Simple stacking of plates in which strain vectors cancel each other is one type of group accommodation. There are also more complex mechanisms of strain accommodation that will not be discussed in this work [3,4,5]. Also, in Ti-Ni alloys, individual martensite plates have a strain

accommodating substructure known as twinning [2]. Figure 3 is a transmission electron photomicrograph of internally twinned martensite plates in 50 percent Ti-50 percent Ni. During deformation, martensite plates will detwin to accommodate stress.

Reversion stress and reversion strain are two parameters which characterize the shape memory phenomena. A SMA specimen constrained against recovery during heating through the P_s to P_f temperature range develops an internal stress, known as the reversion stress. When later deformed and heated while unconstrained, the reversion stress produces reversion strain that can be observed as a change in the shape of the deformed specimen. To increase reversion stress, and thus increase the work output of a specimen upon heating, a sample specimen to be formed for a particular use should be strained up to its strain limit. Figure 4 shows that the percentage of recoverable strain for a SMA specimen is a maximum for an induced strain of up to the strain limit, typically about 8 percent. If the initially induced strain is greater than the strain limit, the reversion stress and the recoverable strain, and consequently the useful work output, decreases [2].

The ambient temperature at which the SMA actuator resides is important to the design of actuators because of the temperature dependence of the parent to martensite transformation and its reverse, the martensite to parent transformation.

Figure 5 shows stress-strain diagrams for a SMA at two different ambient temperatures. Figure 5a is the stress-strain diagram for an actuator at an ambient temperature above M_s and below P_f . Two parameters are introduced to describe the transformation stresses and their values reflect the stability of the parent phase material. The stress required to stress induce martensite, s_{p-m} , is a function which linearly increases from a minimum at M_s to a maximum at P_f . When stress reaches s_{p-m} the alloy will begin to experience strain and will transform from the parent phase to the martensite phase. For the martensite-to-parent transformation to occur, the stress level must drop to s_{m-p} . If the stress level is decreased to s_{m-p} there will be an elastic recovery to a lower strain. This is called the pseudoelastic effect, PEE. Further recovery will occur on heating the actuator--the shape memory effect [2]. If the ambient temperature is below the martensite finish temperature, as in Figure 5b, no elastic behavior will occur on unloading the actuator. Recovery will occur on heating only.

Reversion stress has been found to be well approximated by the value of the flow stress s_{p-m} [2]. Flow stress is obtainable from simple tensile tests as a function of temperature and strain. Perkins [2] reported that reversion stress will be about 20 percent lower than flow stress

for a given temperature and strain. This information can be used during the design of a functional SMA actuator.

The temperature dependencies discussed above must be taken into account by the designer of mechanical systems with SMA actuators. Particular attention must be paid to the temperature dependence of the flow stress and reversion stress. Reversion stress is a maximum over only a small temperature range near P_f [2]. If, during heating, the stress on the SMA actuator exceeds the parent phase yield strength so that yielding occurs there will be a decrease in reversion stress which will continue to decrease as the temperature continues to rise [2]. Accompanying the decrease in reversion stress may be a conversion of part of the initial strain into permanent damage in the form of plastic strain. A second problem situation occurs if a constant load is maintained on the SMA as the temperature approaches M_s . Since s_{p-m} is low at M_s the applied stress may produce true plastic deformation of stress-induced martensite [2].

A specimen, if cycled many times, may develop a partial two-way shape memory, that is, the SMA will have one remembered shape in the high temperature phase and a second remembered shape in the low temperature phase. A detailed review of the mechanisms of two-way shape memory may be found in references [6,7,8]. However, some observations on two-way shape memory (TWSM) training are appropriate.

From a study of TWSM training routines, Perkins and Sponholz [6] reported some factors which contribute to the improvement of TWSM. Deformation beyond the strain limit of the sample in its initial training cycle was a requirement for TWSM. As a sample undergoes an increasing number of work cycles, some martensite structures may be retained in the sample even in the parent phase. This retained martensite does not now have to be induced in later training cycles and the training process becomes easier. Perkins and Sponholz [6] postulated that the retained martensite may serve as nucleation sites for the thermoelastic martensitic transformation discussed above. Through plastic deformation and retained martensite, the parent phase matrix may adjust so as to nucleate and grow a particular and preferential variant of martensite. This substructural adjustment becomes more refined as cycling continues.

Optimum training for TWSM displacements will be realized when an SMA, initially in the parent phase, is subjected to some plastic deformation during the first cycle which is followed by approximately 15 training cycles. The training cycle displacements should be at least 2 times greater than the TWSM cool temperature working displacement [6]. Specific TWSM training routines are given in [2 and 6].

III. EXPERIMENTAL APPARATUS

The SMA testing apparatus consisted of an electrical heating system, a fluid flow system, and a data acquisition and control system. Each of these systems will be described. Letters in parentheses refer to Figure 6, which is a schematic diagram of the SMA testing apparatus.

A. ELECTRICAL HEATING SYSTEM

An electrical system was built to heat the SMA coil sample, control the amount of heat applied to it, and measure the power consumed by the coil during heating. The SMA test coil was resistively heated as electrical current was passed through it. A 25 VDC variable power supply (A) was used as the current source. A precision 2 ohm resistor (B) was connected in series with the SMA coil. Using the measured voltage drop through the resistor (V_g), the current through the coil was calculated. A switch (C) was installed in the circuit for manual control of power to the coil. A 125 VDC, 1 amp relay (D) was installed to permit computer control of power to the coil. The SMA coil was connected in the electrical circuit by two 3/8 inch diameter, 1/8 inch thick copper discs (E). The coil leading ends (F) fitted into a centered hole in the discs and were anchored by set screws. The positive electrode was fixed to an L bracket (G) which was attached to the

supporting structure. The negative electrode (H) remained free to travel with the recovering SMA coil. It was sandwiched between two insulating phenol discs, each 1/2 inch diameter and 1/16 inch thick. The return wire (I) emerged from the copper disc through the center of the second phenol disc.

Displacement of the SMA coil during actuation was determined through the use of a 10 turn linear potentiometer (J). A soft rubber, center grooved, grommet (K) was mounted to the potentiometer arm on a teflon disk. A wire string (L) ran from the negative electrode (H), over the potentiometer arm, to a plate (M) which carried loads applied during test runs. Voltage across the variable resistor (V_7) was measured by the data acquisition system as the potentiometer arm turned as the SMA recovered or reextended.

B. FLUID FLOW SYSTEM

A constant flow rate fluid system using water was constructed to provide cooling water to the SMA coil. The head tank (N) was fitted with an overflow (O) to the system reservoir to maintain a constant head, and thus, constant flow rate. An immersion heater (P) was installed in the head tank, supported by the tank top to preheat the water. A type T thermocouple was installed in the head tank near the flow exit of the tank (T6). A Fisher-Porter rotometer (Q) with a ball float was installed in the system between head tank and the SMA cooling chamber.

The SMA chamber (R) served as a mechanical support for the SMA coil and as the cooling chamber when water cooling was applied during test runs. A photograph of the SMA chamber is provided in Figure 7. Referring to Figure 6, type-T thermocouples were installed near the inlet (T1) and outlet (T2) of the chamber through holes in the tubing. Three type-T thermocouples were affixed to the SMA coil (T3, T4, T5) with small strips of heat-shrinkable tubing, and emerged from the chamber through a Swagelok fitting (S).

After passing through the SMA chamber, water flowed into the system reservoir (T). A small electric submersible pump (U), capable of 1/70 HP, was sufficient to maintain the head tank water level for the flow rates used in the investigation.

C. DATA ACQUISITION AND CONTROL

The data acquisition and control system was centered around an HP-9826 computer, an HP-3497A data acquisition system, and an HP-6942A multiprogrammer. A block diagram of the data acquisition and control system, as well as a data reduction flow chart, is provided in Figure 8. All computer programs written for the HP-9826 used the Basic programming language and are included in Appendix B. Programs written for data reduction using the IBM 3033 used Fortran and are included in Appendix C.

Program 'SMA' directed electrical system control and data acquisition. Sets of data were taken by the HP-3497A

as directed by 'SMA'. Data accumulated in each set included coil position, coil current and voltage drop, and all thermocouple outputs. As indicated in Figure 8, the initial portion of 'SMA' was interactive, requiring operator input of the total number of samples, TT, for each test run and the interval between each sample set, t. The total time between sets of data, including data acquisition, the programming loop and the wait interval, was measured as 2.075 seconds by the HP-9826 internal clock.

Program 'SMA' directed electrical power to the coil by closing the relay installed in the electrical system (see Figure 6). This was accomplished through a relay card on the HP-6942A multiprogrammer. 'SMA' directed closing of the HP-6942A relay which, in turn, completed the required circuit to close the electrical system relay. With that relay closed, power was available to the test coil. Power to the coil was disconnected when 'SMA' directed the multiprogrammer to open its relay.

Program 'SMA' directed the HP-3497A data acquisition system to sample each of the nine system voltages every t seconds. The sampling time for each channel of the HP-3497A was 0.04 seconds, for a total sampling duration of 0.44 seconds. After sampling, the HP-3497A was directed to send the data to the HP-9826 for storage. The type-t thermocouple voltages were converted to temperature in degrees Celcius using the fourth order least squares coefficients

given by Beckwith and Buck [10]. Potentiometer voltage, V_7 , was converted into distance using the linear relation developed as a result of calibration of the potentiometer. Appendix D contains the calibration coefficients for this potentiometer. Current through the circuit was calculated using the voltage drop, V_8 , across the precision 2 ohm resistor. Power to the coil was calculated using the voltage drop across the coil, V_9 , multiplied by the calculated current. This data was written to a disk file by the HP-9826.

IV. EXPERIMENTAL PROCEDURE

The experimental procedure consisted of three basic steps: SMA sample preparation, SMA sample testing for response, and the measurement of temperature distributions along the sample.

A. SMA COIL PREPARATION

A SMA spring-like coil shape was chosen for testing because of the anticipated use of this shape in a robot arm. For use in the SMA chamber the coil was required to have a section of straight wire at both ends leading to the coil. The straight coil ends were required so that they would travel freely through the SMA chamber ends.

Raychem Corporation of Menlo Park, California, provided samples of 50 percent Ti-50 percent Ni wire of various diameters. Wire with a diameter of 0.53 mm (0.030 inch) was chosen for use because its malleability allowed for easy coil formation. Also, less power was required to heat wire of this diameter than larger diameter wire.

The Ti-Ni wire was locked into spring-like coils with straight sections at both ends by using a specially designed mandrel. The mandrel was a threaded rod, with special nuts used for locking the wire during the shaping process. The coil forming rod can be seen in Figure 9a. The rod formed a 1 inch long coil with 20 turns per inch and lead sections

of 3.5 inches long at either end of the coil. Wire was wound on the rod as the rod was hand turned on a lathe. The coil was locked at both ends with the set nuts. The leading ends were strained to approximately 4% then locked in place at the end of the rod. Leads were pressed into grooves cut into the rod with plates as seen in Figure 9b. During the heat-treating process, the plates were clamped tight into the grooves to prevent recovery to the factory-induced shape of the Ti-Ni wire that existed as it was first heated.

To heat-treat the wire, the entire assembly was placed into a 320°C oven for 15 minutes. After removing the assembly from the oven the assembly was quenched in ice water.

After heat-treating the SMA coil leading ends were checked for the proper straight shape. The locking nuts on the end of the rod were removed and those at the end of the coil remained in place. The leads were bent out of the rod groove, then heated to review their recovery. If the leads did not recover a straight configuration that would slide through the SMA chamber end readily, the shaping process was repeated for the leads. With the coil still locked in place, the leads were further strained and then locked in. Heat-treating and shape checking were repeated as discussed. Satisfactory coils and leads were generally obtained after repeating the process two or three times.

B. SMA COIL EXTENSION, ACTUATION, AND DATA ACQUISITION

Tests were conducted with single-cycle and repeated-cycle runs. Single-cycle extension runs included extension of the SMA coil, actuation and recovery of the coil, and cooling. Repeated-cycle runs merely repeated this sequence more than one time during a sample run.

1. Single-Cycle Tests

The primary purpose of the single-cycle runs was to identify the maximum temperatures reached during SMA recovery and to compare coil rate of recovery at various current inputs. Work done by the coil was also of interest and was easily calculated from data taken during the single-cycle runs.

A single-cycle of a test run contained the following steps.

- a. Apply the load. The desired load was placed on the load plate. The applied load varied from no load on the plate to 1.96 Newtons. The mass of the plate (refer to Figure 6) and wire string was 31 grams.
- b. Extend the SMA coil. The coil was extended by the operator until the coil reached the end of the cooling chamber. Figure 6 shows the coil in its extended, deformed, position.
- c. Set desired current. The desired current input was adjusted by the operator at the power supply.

- d. Initiate computer control. For this phase of the tests a single step, constant current input heated the SMA sample. Program SMA (refer again to Figure 7) was configured to take two sample sets, then close the relay to apply power to the SMA coil. The relay was not opened by computer control until the final sample was taken.
- e. Cut power-off. Power was manually cut off by the operator, using the installed switch, when the coil reached maximum recovery. Data acquisition continued whether power was applied to the coil or not. The total number of sample cycles for each run could be varied by interactive computer control, but generally, 100 samples of each parameter were taken. Sufficient data was obtained from the recovery phase and cool-down period.

2. Multiple-Cycle Tests

This phase of the testing involved a repetition of the single-cycle tests within the same run period. The most effective use of the multiple cycle tests occurred when no cooling water was present in the cooling chamber at the start of the run. The cycle was initiated as above, then when the actuator reached full recovery the operator cut off power to the system and initiated fluid flow through the

chamber to cool the actuator. Once the actuator had cooled, as recognized by its reextension, coolant was cut off and power reinitiated to start the next recovery cycle. The cycle was repeated as often as possible during the run period. Once again, 100 sample sets was used as the total number of samples taken.

V. DATA REDUCTION

Data reduction included transferring data obtained during runs of the SMA testing system from floppy disk storage on the HP-9826 microcomputer to the IBM 3033 computer and then obtaining data listings or graphic output. Refer to Figure 8 during the following discussion. Programs written in the Basic programming language are included in Appendix B. Programs written in Fortran are included in Appendix C.

Transfer of data from floppy disk to the IBM 3033 was accomplished by two terminal programs. Program SEND_DATA utilized the Binary Enhancement Basic program available on the HP-9826 to communicate with the IBM 3033 via modem. This program read data files from disk and transmitted data, one number at a time, to the IBM 3033. Fortran program GRAB, run on the IBM 3033, received the transmitted data and wrote it to a disk data file for storage.

Program REARRANGE was then used to reorganized the data file from a single string of numbers to nine columns of numbers corresponding to the nine measured parameters of the SMA testing system. After rearranging, the data files were easily used as input to other data reducing programs.

Three programs were used for producing graphic output of the data. SMA3, LOGGRPH, and TEMGRPH were Fortran programs that used the Display Integrated Software System and Plotting

Language (DISSPLA), by Integrated Software Systems Corporation of San Diego, CA, resident on the IBM 3033. DISSPLA is a library of Fortran subroutines that can be used in Fortran source code to generate graphical output. Since DISSPLA is computer and device independent, programs developed in this work may be converted for use at other installations having DISSPLA.

Program SMA3 was written to present data from different test runs side by side (see Figure 10). Generally, for each run two data plots were presented. The first was a plot of temperatures along the SMA coil. It included T3, T4 and T5, and the cooling water temperature, or ambient temperature, T2, if water cooling was not used, as functions of time (Fig. 11a). The second was a plot of current, power, and SMA coil displacement as a function of time (Fig. 11b). These plots were used to identify the cooling period of each test run for further data reduction. Figures 12, 13, and 14 have been annotated to identify the cooling period which became the focus of further data reduction.

Since the SMA test system was a thermal system, and SMA coil displacement versus time curve was exponential in appearance, the system was considered to be a first order system. Output of this system was SMA coil displacement, in recovery or in reextension, according to the relation:

$$c(t) = 1 - e^{-t/T} \quad (t > 0)$$

where $c(t)$ = coil displacement divided by maximum displacement

T = the system time constant

t = time since zero

In order to verify that cooling of the SMA coil was, indeed, first order, and to compare water and air cooled coil performance, the coil time constant was calculated for each test run. The natural logarithm of normalized displacement during the cooling period was plotted as a function of time and the first order system time constant, T , was determined from such a plot as:

$$T = -1/\text{slope}$$

Fortran program POLYFIT was used at this point to determine a linear fit to the natural logarithm of normalized data during the cooling period. Displacement was normalized by dividing the displacement value at time t by the maximum displacement at recovery. In the cooling phase, then, normalized data would decrease from 1.0 to some value which is a percentage of the total possible recovery displacement. The percentage of possible reextension is one minus that value.

Data points were determined for each run using SMA3 graphs and the data listings from which they were generated. Figures 12b, 13b, and 14b, indicate that the coil did not immediately begin to reextend when power was cut-off. These represent coil recovery by stagnant air, natural convection to air,

and water cooling, respectively. As can be seen from the corresponding temperature versus time graphs, the temperature decreased prior to reextension. With that in mind, the data files were examined to isolate the beginning and end of the coil reextension period. For RUN 81 and RUN 85, Figures 12 and 13, respectively, the cooling period included the remaining time of the run after power to the coil was turned off. In Figure 14 of RUN 194, and similarly in other test runs which used water cooling, the cooling period included only four data points. The final data point for inclusion in the linearity calculation was determined as the last data point to be 0.05 cm greater than the following point. At that point the SMA coil had nearly reached its limit of reextension determined by the load and the temperature of the cooling water. This data was fed into POLYFIT which normalized the displacement and then calculated the natural logarithm. POLYFIT then used these numbers to make a first order curve approximation to the data and output the coefficients of the curve fit:

$$\ln(X/X)_{\max} = A_1 + A_2 t$$

where A_1 = the y intercept

A_2 = the slope of the curve and is equal to $1/T$

X = the displacement

t = the time

POLYFIT also output a set of data points which corresponds to the curve fit described above.

Program LOGGRPH was used to compare POLYFIT output for different SMA test system runs. LOGGRPH used the raw log normalized data and the curve fit data developed in POLYFIT to produce graphic output of the type seen in Figure 15. The linear nature of these curves confirms that the SMA test system is a first order system [11]. And from the curves, the time constants of the system under different cooling conditions were easily compared.

Program TEMGRPH was written to examine the recovery or reextension displacement of the SMA coil as a function of the coil temperature. The temperature dependence of coil recovery and reextension displacement is a characteristic that must be used in the development of feedback control of future SMA systems. Figure 18 is a displacement-temperature graph produced by TEMGRPH.

VI. RESULTS

The results of this investigation into different methods of cooling the SMA coil after coil recovery can best be seen graphically in Figures 10, 11, 15 and 19. A description of these figures and some additional observations follow.

A. SMA COIL IMMERSSED IN WATER

Electrical heating of the SMA coil immersed in water produced no coil recovery. Figures 10 and 11 represent data obtained from two SMA test runs in which the coil was immersed in stagnant water during the entire time of the run. During RUN 82 shown on Figures 10a and 10b, 6 watts of electrical power at 2 amperes was applied for 200 seconds. The water temperature was initially at the room temperature of 22.8°C and rose to 27.3°C by the end of the run. During RUN 138 shown on Figures 11a and 11b, 2.5 watts of power at 1.25 amps was applied for 200 seconds. The water in the chamber had been preheated to 45°C and rose to 47°C during the run. In each case, it can be seen that no coil recovery displacement resulted from the electrical heating. Due to the large amount of heat transferred from a coil to a surrounding liquid, it was not possible to actuate an SMA coil immersed in water. The technique employed in later experiments was to initially heat the coil with only air

present in the chamber. Water was then added to quickly cool the coil causing it to revert to its original shape. This technique dramatically increased SMA coil cycle time.

B. SMA COIL COOLED UNDER THREE CONDITIONS

Data was compiled as described in the experimental procedure using three different cooling conditions for the SMA coil. The primary goal of the data reduction was to determine the coil cooling time constant, T , for the SMA coil as it is cooled in the chamber with no coolant, by natural air convection, and by water cooling. This time constant reflects the displacement of the coil with respect to time. Figure 15 is a plot of the natural logarithm of the normalized coil reextension displacement versus time for three test runs, each of which used one of the three cooling conditions. For each run the applied load on the SMA coil was 1.3 N. The time constant for each cooling configuration can be read from the graph. For the three runs shown, the time constant of the chamber-cooled SMA system with stagnant air as the coolant was 25 times as long as the water cooled SMA system. The time constant for the natural convection air-cooled system was 15 times as long as that for the water-cooled system.

Figure 17 shows time constant data for some additional SMA test system runs conducted with various cooling conditions and various loads. A comparison of time constants for RUN 196

(Figure 17) and RUN 85 (Figure 15), both cooled by natural air convection, and the SMA coil loaded with 1.3 N, shows a difference of 66 seconds between the two. A primary factor in this difference may be the ambient temperature at the time of the run. From Figure 16, it can be seen that the ambient temperature at the time of RUN 196 was 27 C, whereas during RUN 85 the ambient temperature was 22 C. Also from Figure 16, it can be seen that the time constant of the water-cooled system load with 2.0 N, RUN 191, was 2.2 times larger than the time constant for a water-cooled system loaded with only 0.8 N.

In general, the time constant of a water-cooled SMA system was 15 to 25 times faster than a natural air cooled system and 20 to 30 times as fast a closed-chamber system.

It can be seen from Figures 12 and 14 that reextension of the SMA coil did not begin immediately when power was turned off. Note the constant displacement ledge in each figure. Reextension began only when the temperature at the midsection of the coil decreased below 60 C. Also, in Figure 13, where the coil did not reach such high temperatures, reextension still did not begin immediately but accompanied a decrease in temperature below 50 C. However, the delay in this case was much less. By examining the heating portion of the temperature and displacement versus time graphs of Figures 12, 13, and 14 it can be seen that the rate of work output from the coil decreased dramatically

after the coil reached approximately 50 C. This could be expected as a characteristic of this first order system and, also, it corresponded to the approximate austenite finish temperature referred to in the discussion on the material aspects of SMA's. The delay in reextension after recovery is indication that the M_d for this SMA (refer to Fig. 2) was in the 55-60 C temperature range. By plotting displacement as a function of temperature, as in Figure 18, it can be seen that very little displacement per degree was yielded when the coil temperature was above 45 C. This was true for both recovery or reextension.

VII. CONCLUSION

This work has involved the construction of a system for testing SMA actuators under different loads, different actuating electrical current, and different cooling conditions after actuation. Computer control of the SMA testing system and data acquisition system was implemented. Experimentation proved that a SMA system equipped with water cooling provided an actuator cycle time 15 to 30 times faster than a natural air-cooled system or a stagnant air-cooled system.

Recommendations for further study are numerous, and included three major areas of SMA use and control. The first area for study is that of the alloys themselves. For most applications, specific knowledge may be required of the alloy transformation temperature range, the maximum reversion stress, and other alloy characteristics. This information was not available from the alloy manufacturer at the outset of this investigation but could be obtained in local laboratory testing. Also, a more thorough knowledge of two-way shape memory training and strengthening routines is needed to efficiently use SMA actuators. This is required since one-way shape memory induced devices gain two-way shape memory after only a few cycles.

The second area of continuing work would involve adaptation and expansion of the computer control portion of the

SMA testing system for additional modes of control. Current input frequency, step size, and signal types such as a ramp input, may be used to vary the heating of the SMA and, consequently, the performance of the actuator. Computer control of the system using temperature feedback should be tried to prevent overheating of the coil and obtain maximum work output for a given electrical power input.

Finally, the efficiency of the mechanical structures of the testing system should be improved. A more precise potentiometer should be installed. Different actuator shapes and combinations of actuators should be tried. For example, a cluster of small diameter SMA wires may have the same load capacity as one wire of larger diameter, but the cluster will have a time constant many times faster than the single wire [12]. In that case, water cooling or forced air convective cooling is an appropriate consideration for cooling in the system. Study of forced air convection cooling compared to water-cooling and to natural air-cooling should be investigated.

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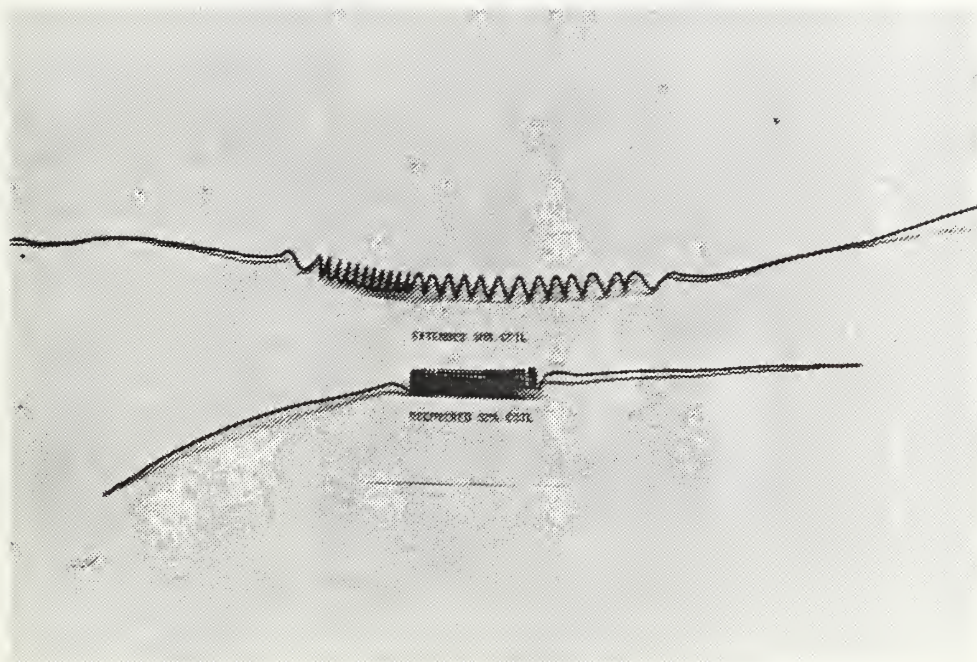


Figure 1. Shape Memory Behavior. A SMA Coil Deformed Will Recover Its Original Shape When Heated

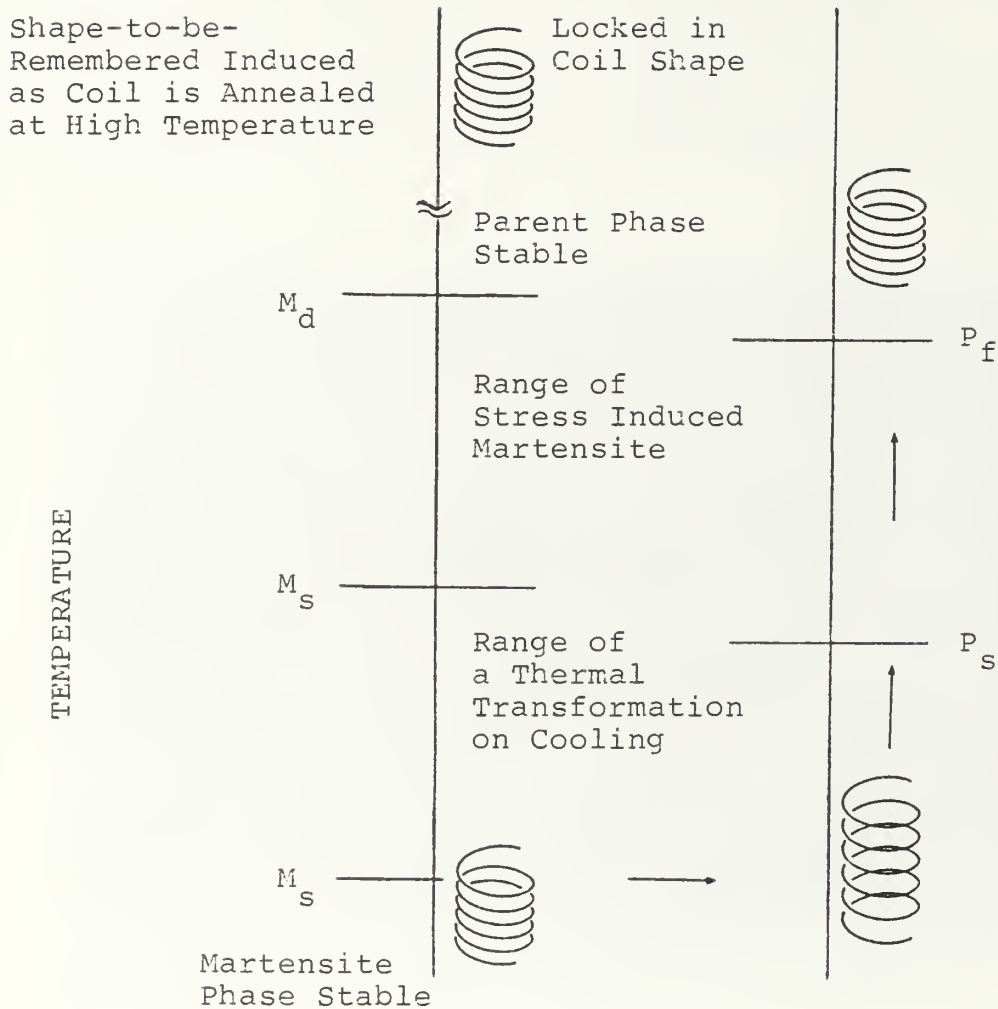


Figure 2. A Schematic Description of the Shape Memory Effect (Adapted from Perkins [2])

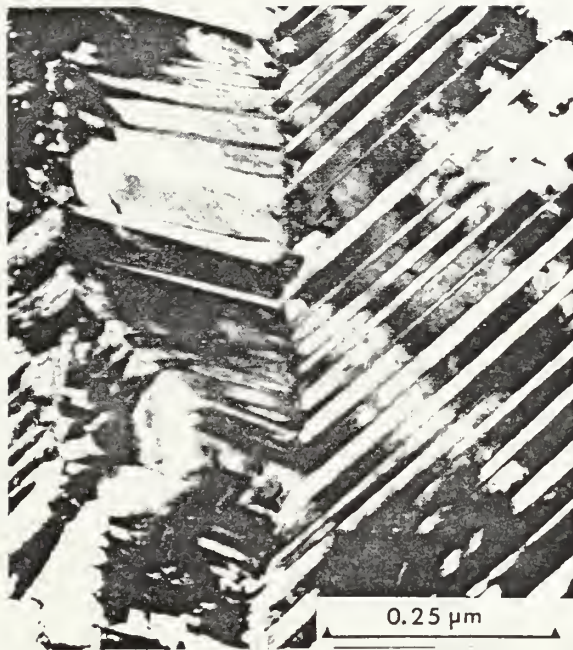


Figure 3. A Transmission Electron Microscopy Photomicrograph of Internally Twinned Martensite Plates (Reprinted with permission [2])

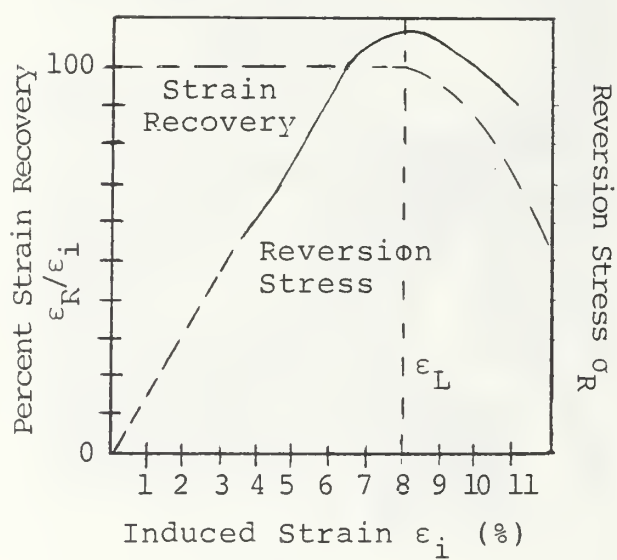


Figure 4. Percent Strain Recovery and Reversion Stress as a Function of Induced Strain (Adapted from [2])

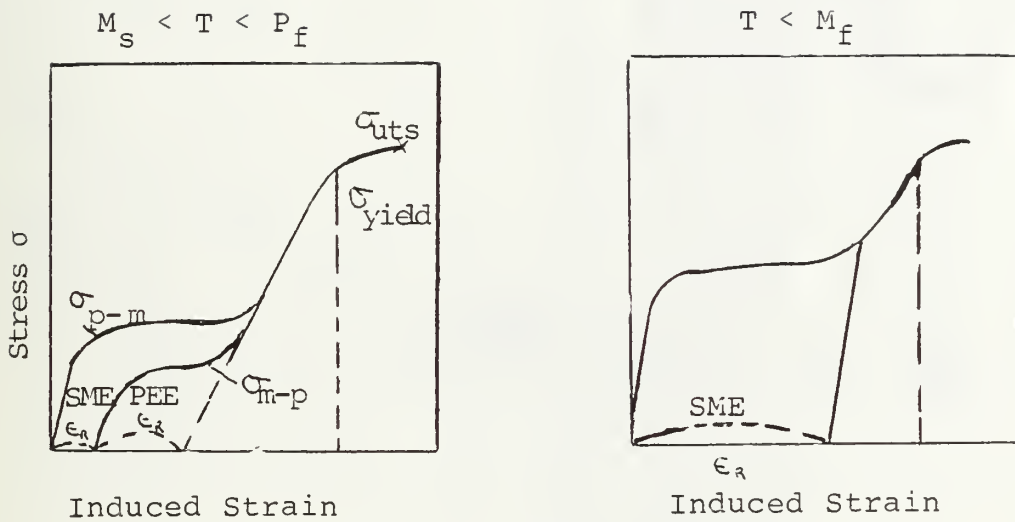


Figure 5. Schematic Stress-Strain Curves for a Shape Memory Alloy at Two Different Temperatures (Adapted from [2])

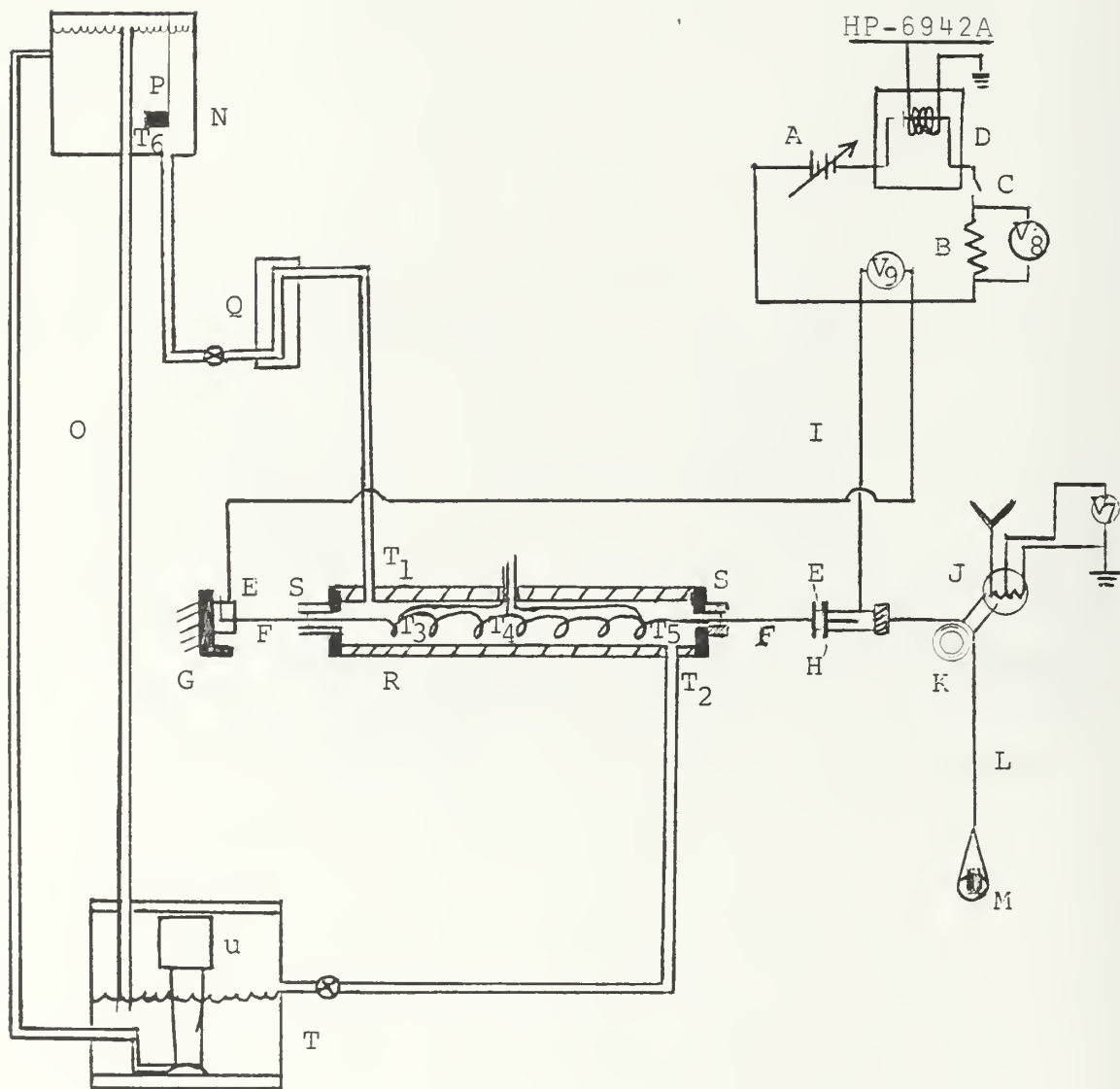


Figure 6. Schematic Diagram of SMA Testing Apparatus

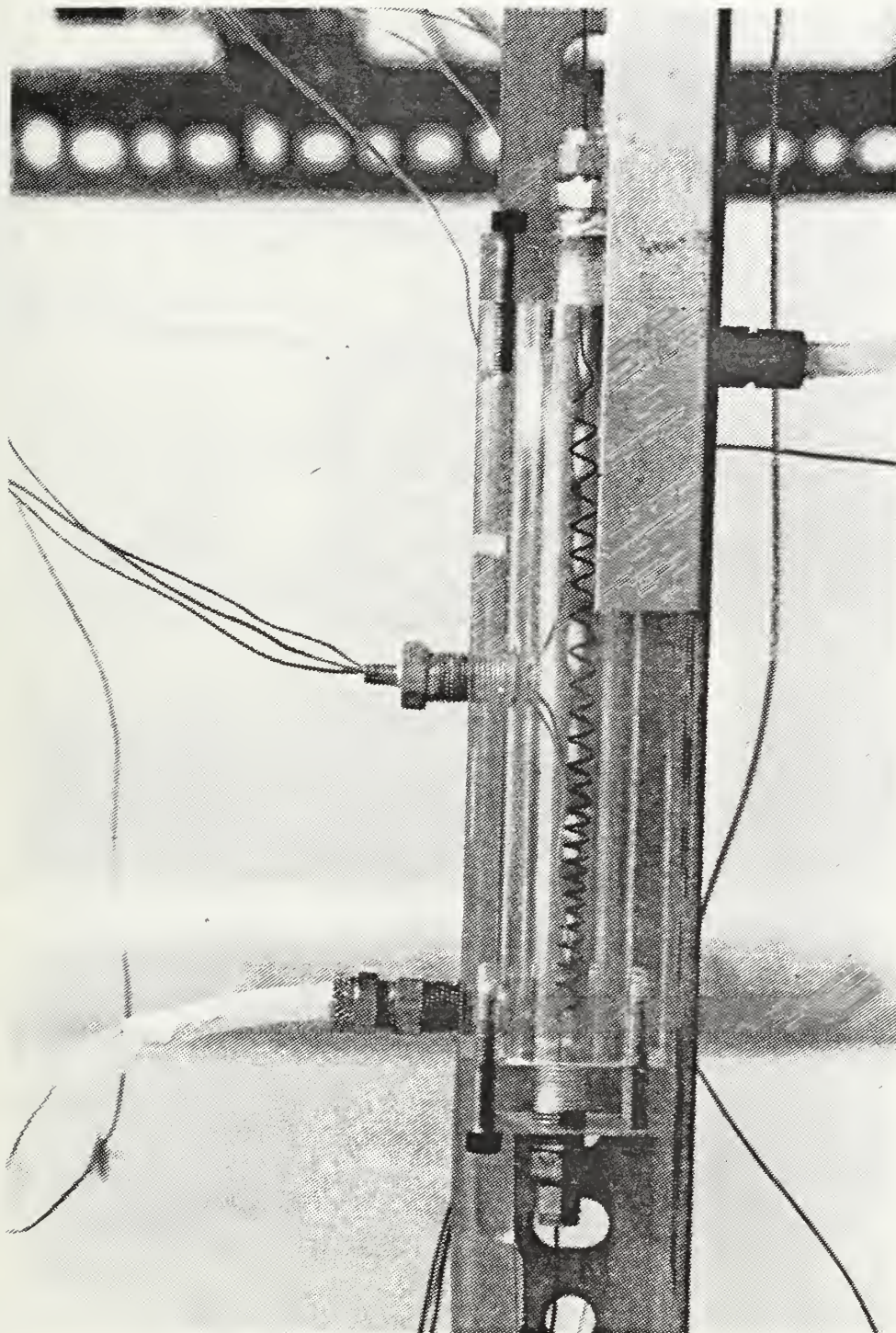


Figure 7. SMA Cooling Chamber

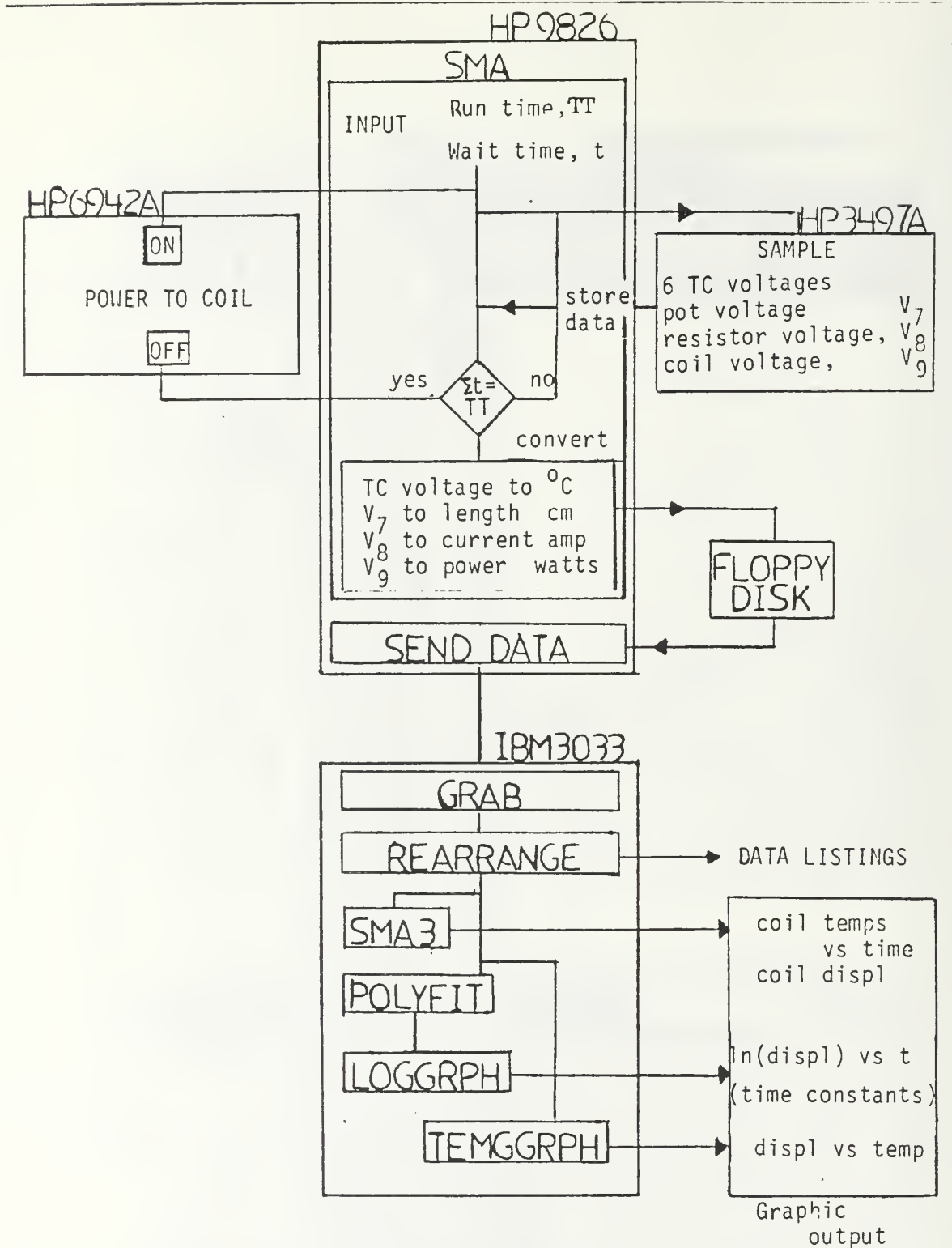
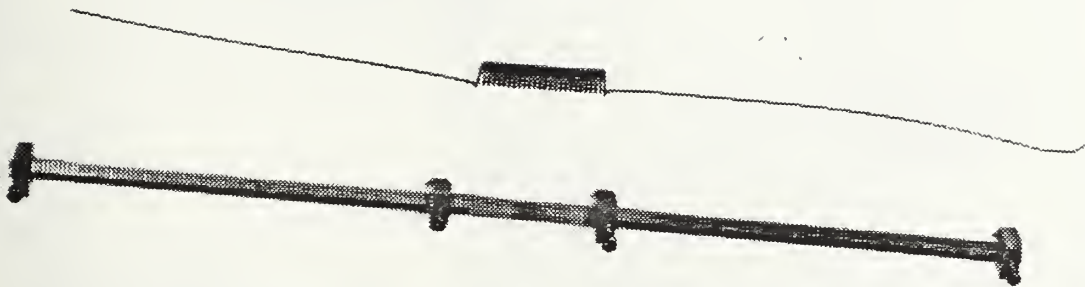
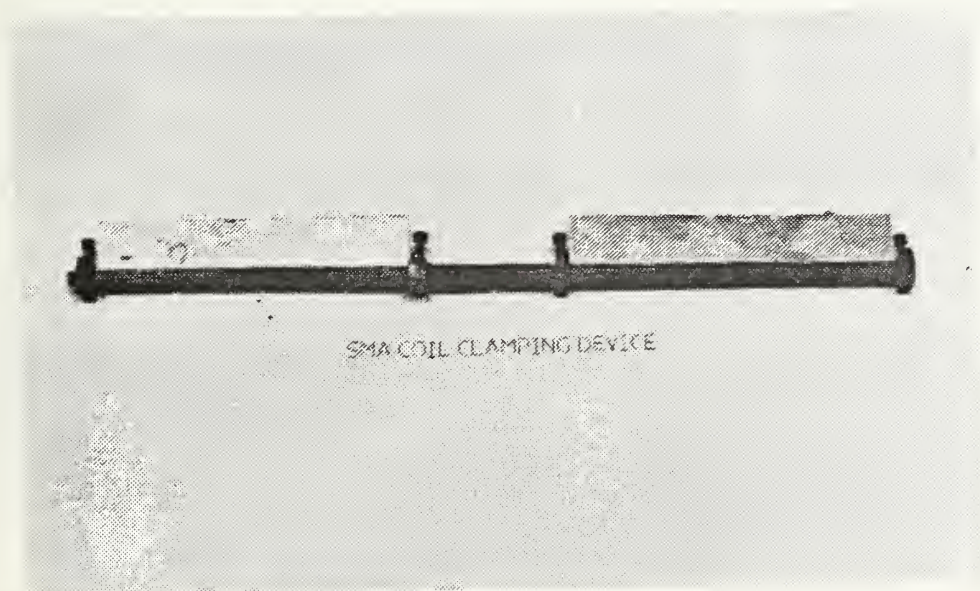


Figure 8. Block Diagram of SMA Data Acquisition and Control System with Data Reduction Process



(a)



(b)

Figure 9. SMA Coil Form Shape Locking Rod

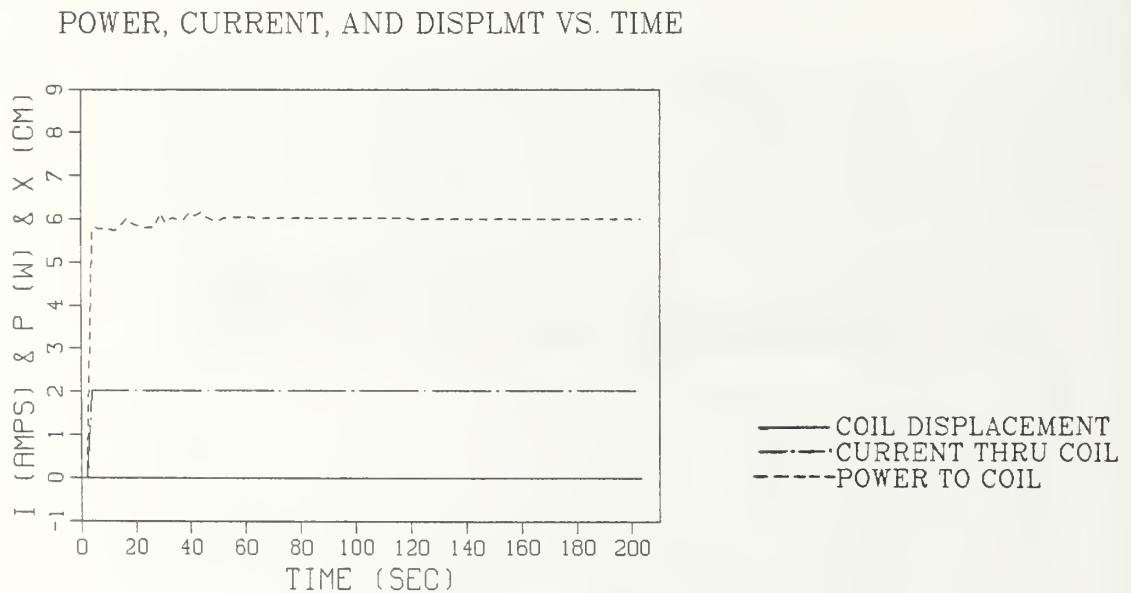
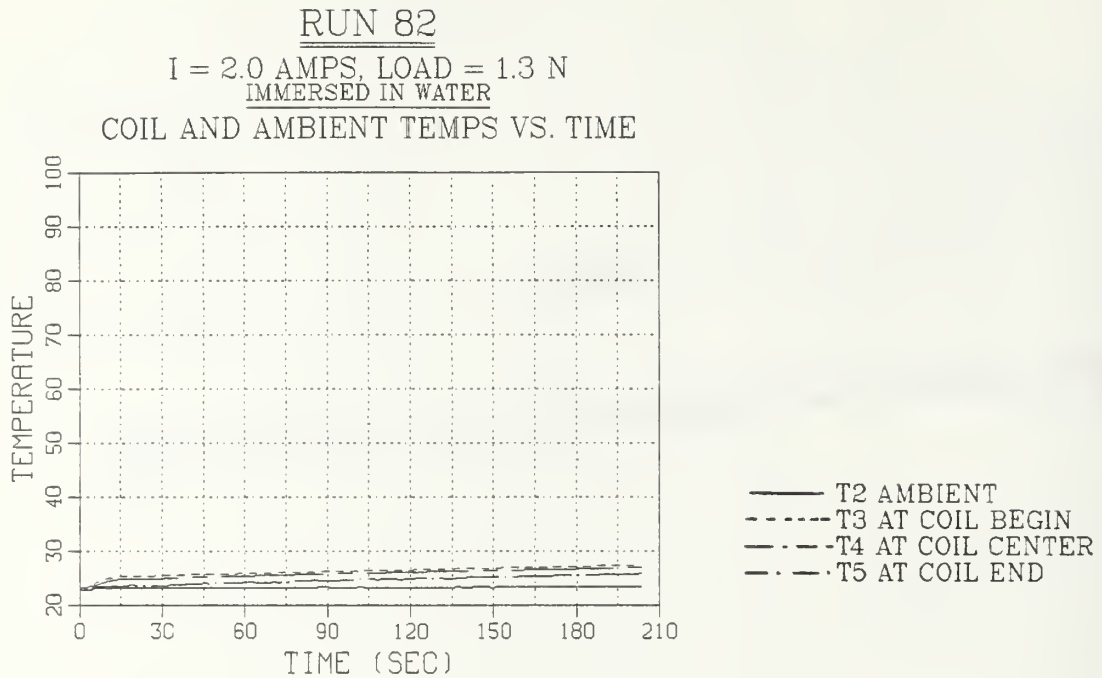


Figure 10. SMA Coil Temperature and Coil Displacement as Functions Run Time for RUN 82

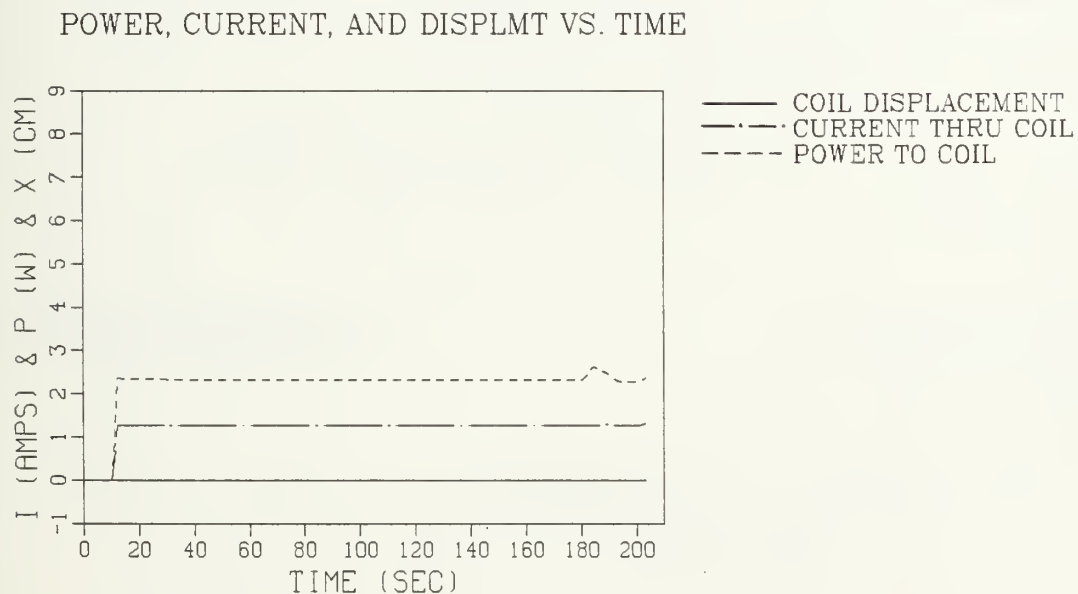
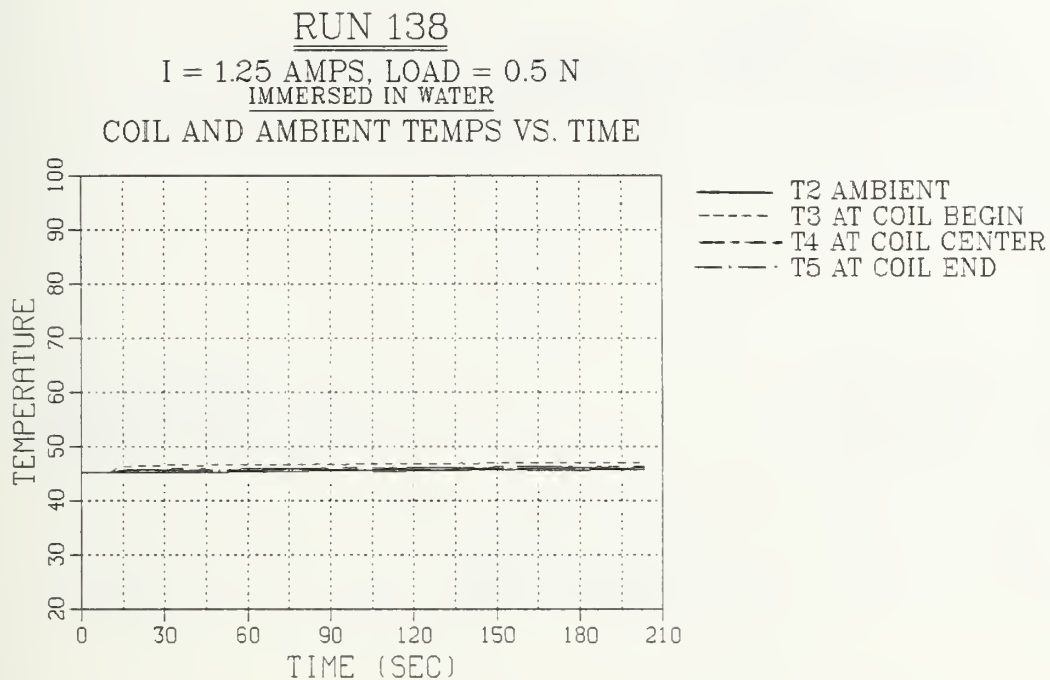
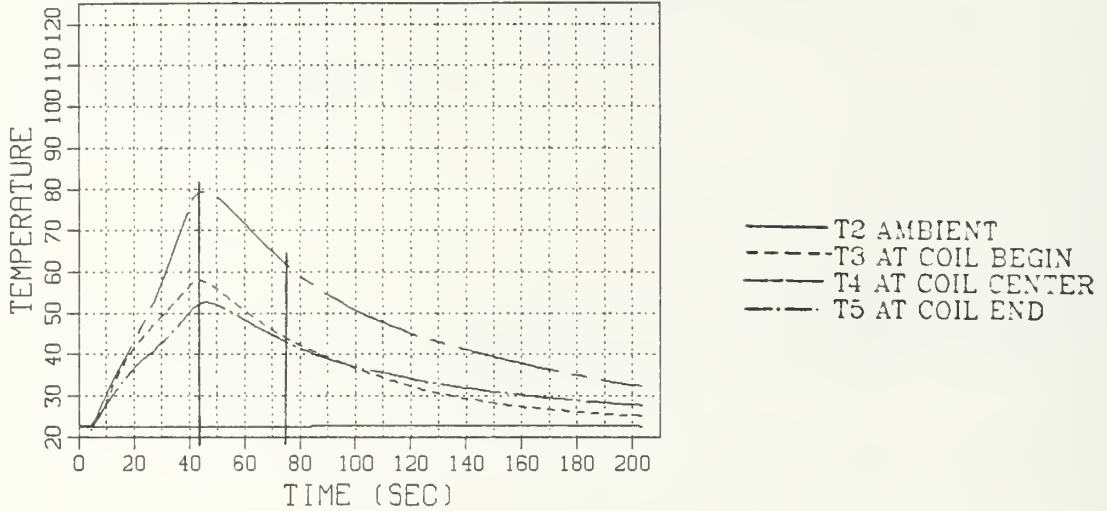


Figure 11. SMA Coil Temperature and Coil Displacement as Functions of Time for RUN 138

RUN 81

I = 2.0 AMPS, LOAD = 1.3 N
COOLED IN CHAMBER, STAGNANT AIR

COIL AND AMBIENT TEMPS VS. TIME



POWER, CURRENT, AND DISPLMT VS. TIME

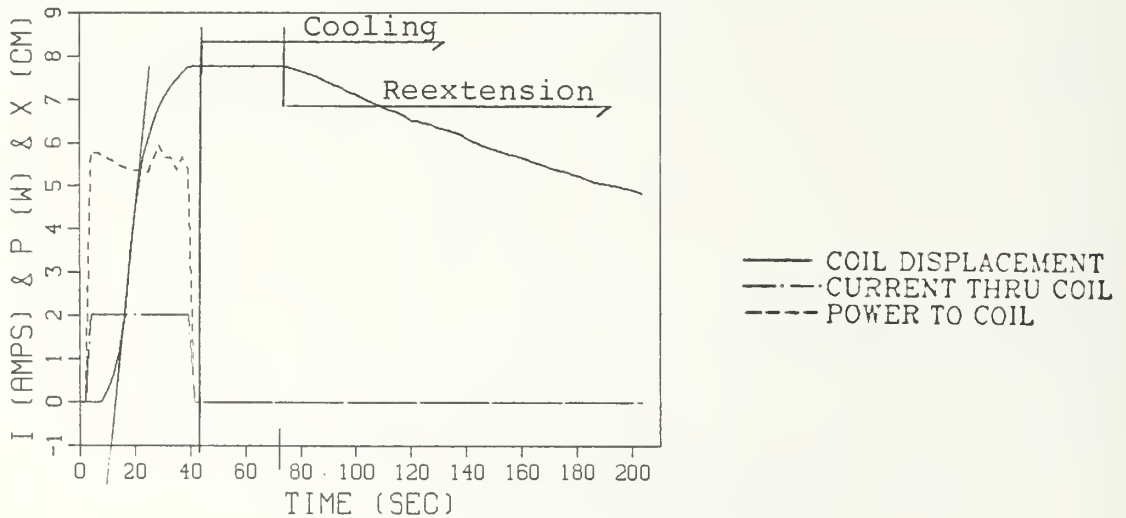
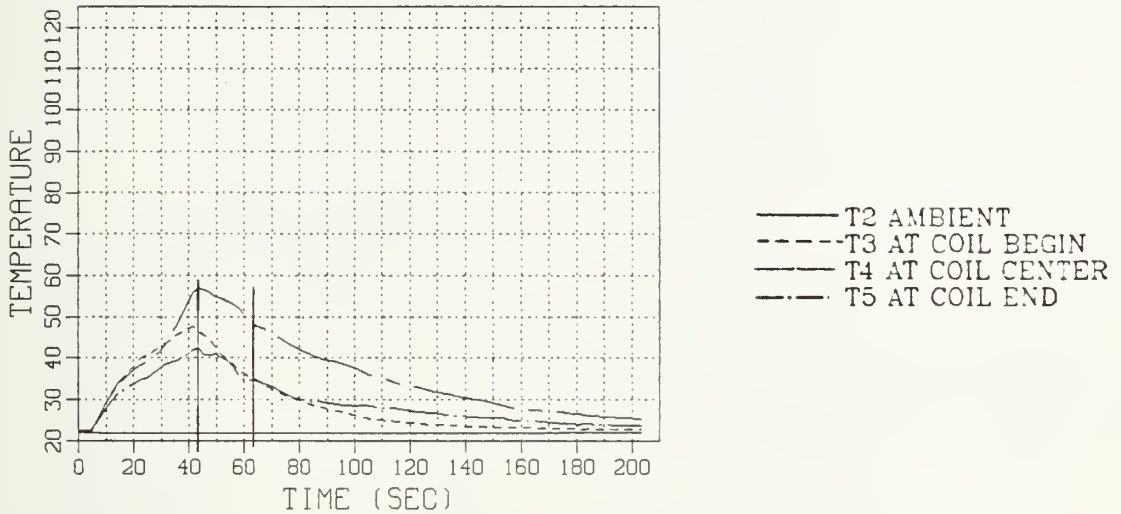


Figure 12. SMA Coil Temperature and Coil Displacement as Functions of Time for RUN 81

RUN 85

I = 2.0 AMPS, LOAD = 1.3 N
 COOLED BY NATURAL AIR CONVECTION
 COIL AND AMBIENT TEMPS VS. TIME



POWER, CURRENT, AND DISPLMT VS. TIME

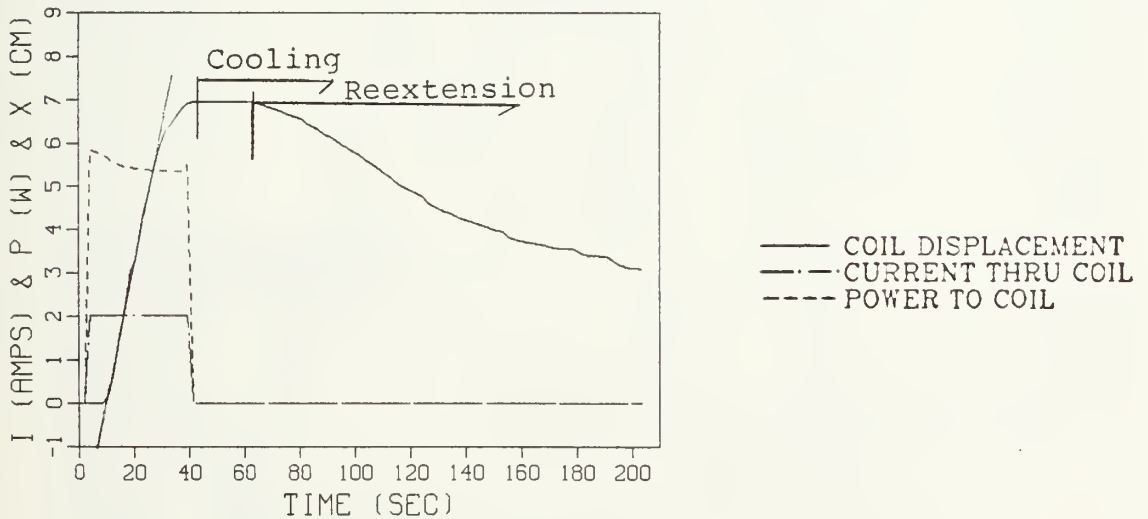


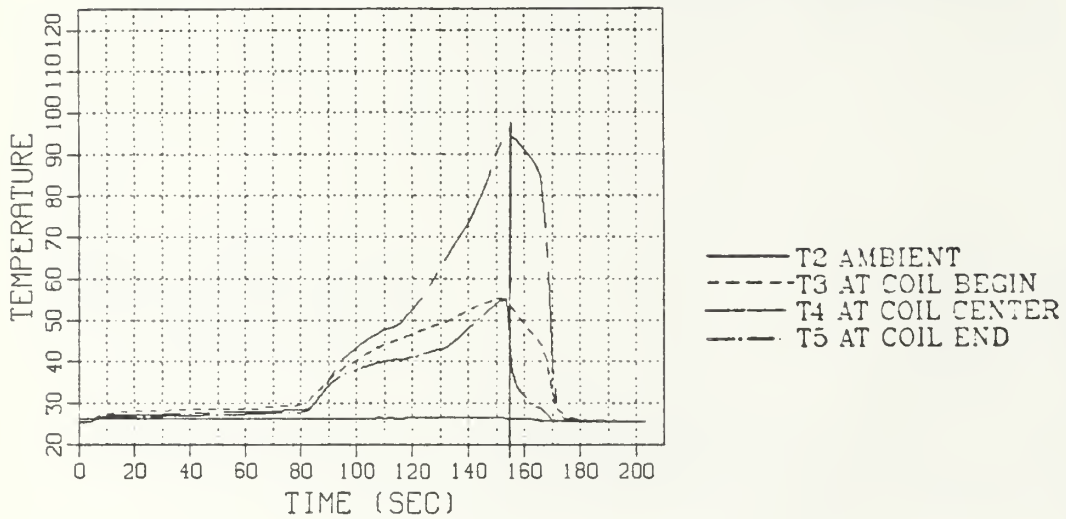
Figure 13. SMA Coil Temperature and Coil Displacement as Functions of Time for Run 85

RUN 194

$I = 2.0$ AMPS, $LOAD = 1.3$ N

WATER COOLED IN CHAMBER

COIL AND AMBIENT TEMPS VS. TIME



POWER, CURRENT, AND DISPLMT VS. TIME

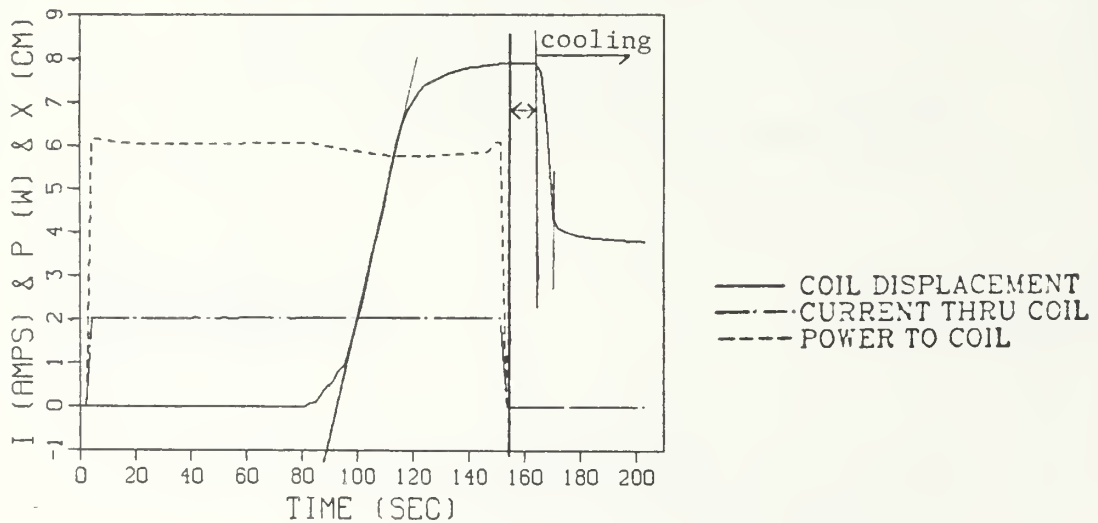


Figure 14. SMA Coil Temperature and Coil Displacement as Functions of Time for RUN 194

LOG OF NORMALIZED SMA COIL DISPLACEMENT VS TIME SMA REEXTENSION DISPLACEMENT AFTER RECOVERY THREE COOLING CONDITIONS AFTER SMA RECOVERY WATER, NATURAL AIR CONVECTION, STAGNANT AIR

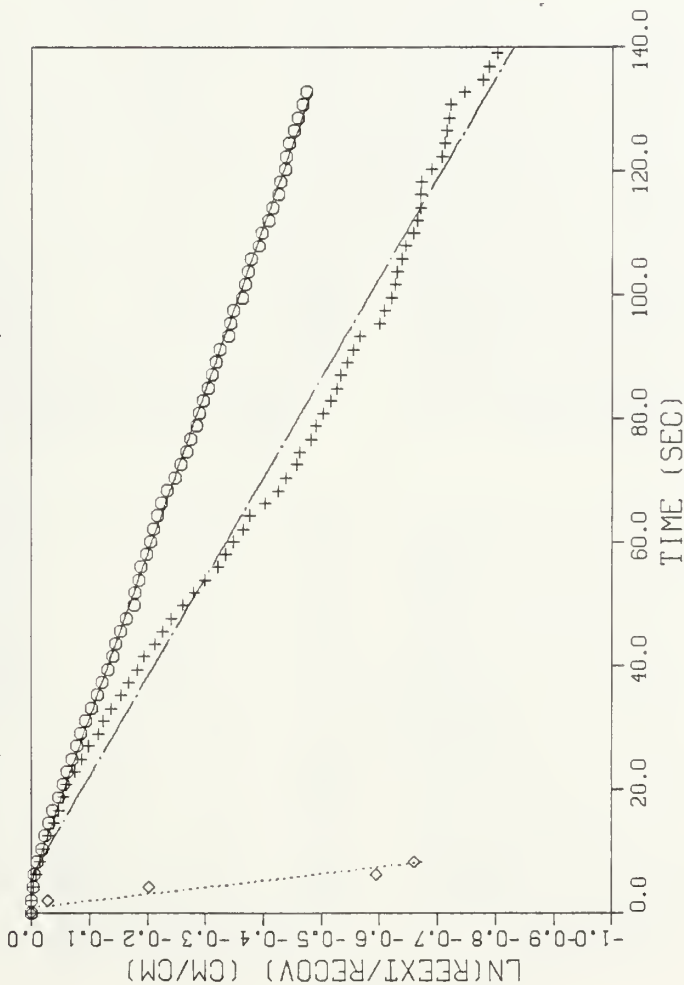
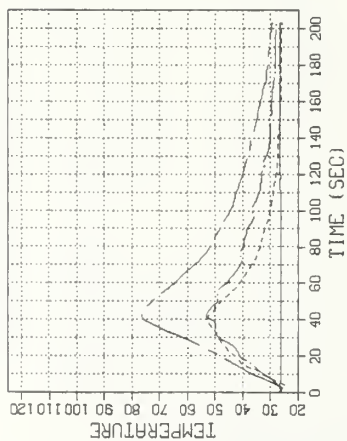


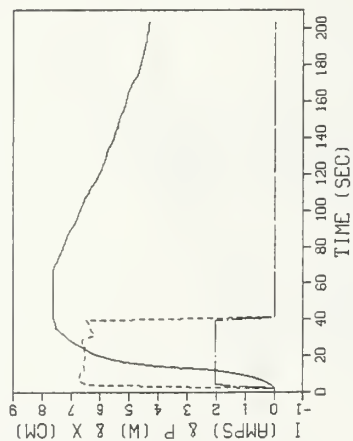
Figure 15. Natural Logarithm of the Normalized SMA Coil Reextension Displacement Using Chamber Cooling, Natural Air Convection Cooling, and Water Cooling

RUN 196

$I = 2.0$ AMPS, LOAD = 1.3 N
COOLED BY NATURAL AIR CONVECTION
COIL AND AMBIENT TEMPS VS. TIME

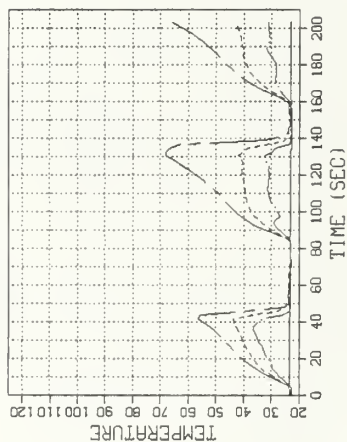


POWER, CURRENT, AND DISPLMT VS. TIME

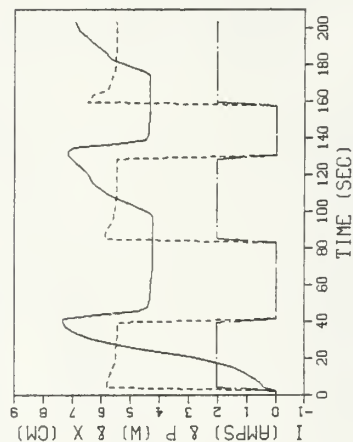


RUN 84

$I = 2.0$ AMPS, LOAD = 0.8 N
WATER COOLED IN CHAMBER
COIL AND AMBIENT TEMPS VS. TIME

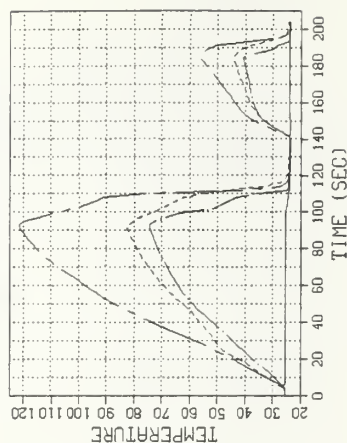


POWER, CURRENT, AND DISPLMT VS. TIME



RUN 191

$I = 2.0$ AMPS, LOAD = 2.0 N
WATER COOLED IN CHAMBER
COIL AND AMBIENT TEMPS VS. TIME



POWER, CURRENT, AND DISPLMT VS. TIME

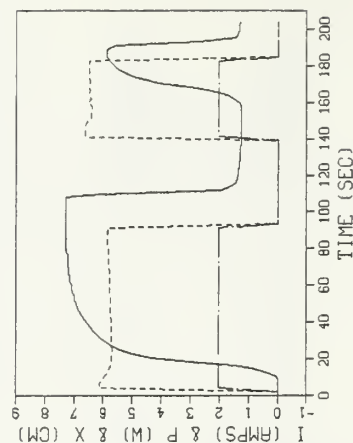


Figure 16. SMA Coil Temperature and Coil Displacement as Functions of Time for RUN 196, RUN 84, and RUN 191

LOG OF NORMALIZED SMA COIL DISPLACEMENT VS TIME SMA REEXTENSION DISPLACEMENT AFTER RECOVERY VARIOUS COOLING CONDITIONS AFTER SMA RECOVERY VARIOUS LOADING CONDITIONS

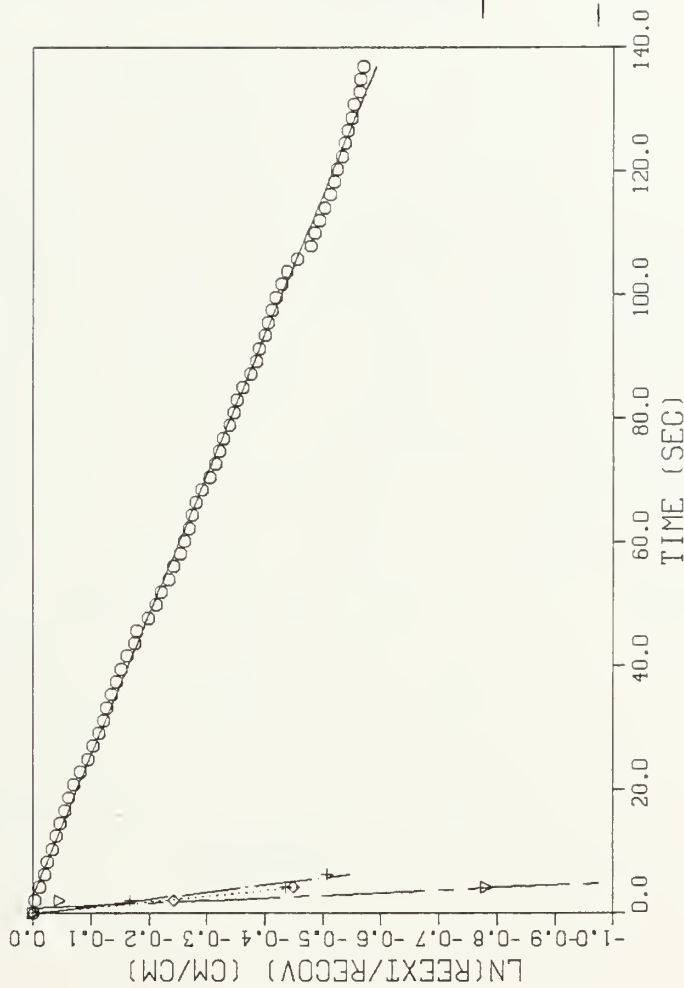
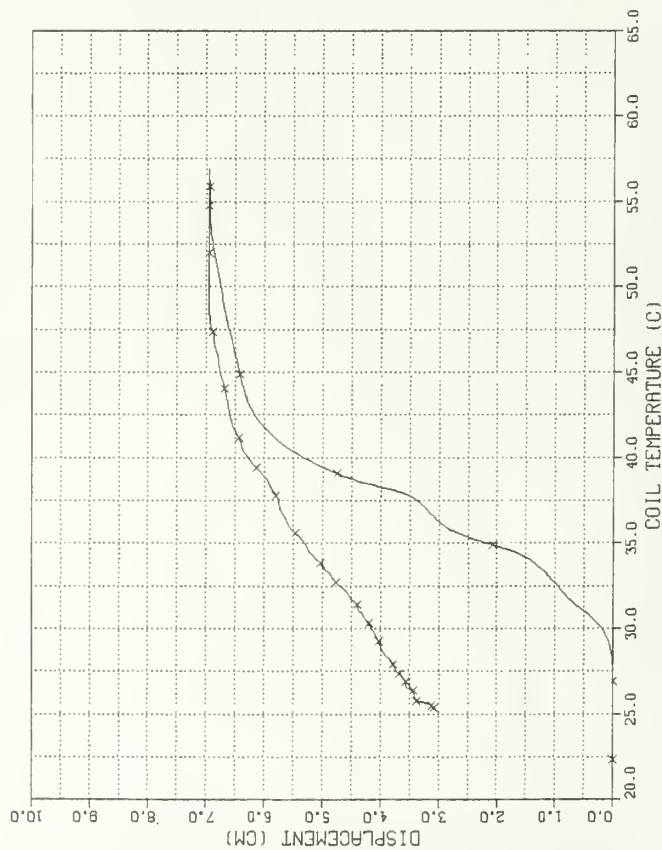


Figure 17. Natural Logarithm of the Normalized SMA Coil Reextension Displacement for Various Cooling and Loading Conditions

SMA COIL DISPLACEMENT VS TEMPERATURE

RUN 85: I = 2.0 AMPS, LOAD = 1.30 N



LEGEND
x - DATA FROM RUN 85

TEMPERATURE DEPENDENCE OF SMA COIL RECOVERY AND REEXTENSION DISPLACEMENT.
RUN 85: THE SMA COIL WAS HEATED BY ELECTRICAL ACTUATION, THEN COOLED IN AIR. NOTE THE DECREASING DISPL/TEMP SLOPE AS THE COIL TEMPERATURE REACHED 42 C, WITH NO DISPL AS THE TEMP ROSE ABOVE 52 C. NOTE ALSO, THE DELAY IN REEXTENSION, DECREASING DISPLACEMENT, UNTIL THE COIL TEMPERATURE REACHED 48 C.

Figure 18. SMA Coil Displacement as a Function of Temperature

APPENDIX A

SMA TEST SYSTEM UNCERTAINTIES

1. Thermocouples: $\pm 0.023^{\circ}\text{C}$
2. Current: $= 0.005 \text{ AMPS}$
3. Voltage: $\pm 1 \times 10^{-6} \text{ V}$
4. Time: $\pm 1 \times 10^{-3} \text{ sec}$
5. Position: $\pm 5.0\%$
6. Load: $\pm 0.10 \text{ Newtons}$

APPENDIX B

BASIC LANGUAGE PROGRAMS USED ON THE HP 9826 COMPUTER

```

10      !Program_sma
20      !
30      !      GOALS:  1.  READ NEARLY SIMULTANEOUSLY
40      !                  a. 6 THERMOCOUPLES
50      !                  b. 1 POTENTIOMETER
60      !                  c. CURRENT (DELTA V)
70      !                  d. VOLTAGE
80      !
90      !                  2.  STORE DATA IN ARRAYS
100     !
110     !                  3.  CORRECT FOR TYPE T-C BIAS
120     !
130     !BEGIN HP 9826 PROGRAM
140     !
150     OPTION BASE 1
160     DIM Data(900,9)
170     PRINTER IS 1
180     !
190     PRINT "time between samples? (sec)"
200     INPUT Delta_t
210     !
220     PRINT "File to dump data to?"
230     INPUT File_name$
240     CREATE BDAT File_name$,50
250     ASSIGN @File TO File_name$
260     !
270     !
280     PRINT "Number of sample sets?"
290     INPUT I_finish
300     PRINT "NOMINAL INITIAL CURRENT IS?"
310     INPUT I_v
320     PRINT "HEATING APPLIED (0=NO, YES,ENTER TEMP)"
330     INPUT Ht
340     PRINT "FLOW RATE IS?"
350     INPUT Fr
360     PRINT "LOAD CONDITION? (MASS ADDED TO PLATE)"
370     INPUT Load$
371     PRINT "MAX EXTENSION AT THIS TEMP?"
372     INPUT Max_ext
380     PRINTER IS 701
390     PRINT "      SAMPLE NO. 1"
400     PRINT "      RUN NUMBER ";File_name$,
410     PRINT "      INITIAL CURRENT =";I_v,"AMPS"
420     PRINT "      HEATING CONDITION ";Ht,"C"
430     PRINT "      FLOW RATE = ";Fr,"ml/sec"
440     PRINT "      LOAD CONDITION IS ";Load$,"GRAMS"
450     PRINT "      NO. OF SAMPLE SETS =";I_finish
460     PRINT "      TIME BETWEEN SAMPLES =";Delta_t,"SECS"
461     PRINT "      MAX EXT OF WIRE AT THIS TEMP = ";Max_ext,"cm"
470     PRINTER IS 1
480     !
490     !
500 Loop:      ! A.  Data Acquisition.
510     !
520     K=K+1
530     BEEP
540     IF K=3 THEN
550     BEEP
560     OUTPUT 723;"0B,1,15,1T"
570     END IF
580     PRINT "Now working on loop ";K
590     !

```

```

600          ! B. Sample all thermocouples.
610          !
620          FOR J=1 TO 9
630              OUTPUT 709;"AI";J
640              ENTER 709;Data(K,J)
650              PRINT "CH";J,"=";Data(K,J)
660          NEXT J
670          !
680          WAIT Delta_t !pause dt secs
690          !
700 IF K<I_finish THEN GOTO Loop
710 OUTPUT 723;"DB,1,15,0T"
720 !
730 ! C. Convert to engineering units
740 !
750 !     1. Read chnl 18-bias for Type E T-C
760 !     2. Read chnl 19-terminal temp(convert to celsius)
770 !
780 OUTPUT 709;"AI18VT1"
790 ENTER 709;Bias_voltage
800 Bias_voltage=Bias_voltage*1000
810 PRINT "BIAS VOLTAGE =" ;Bias_voltage,"mV"
820 !
830 OUTPUT 709;"AI19Vt1"
840 ENTER 709;V_terminal
850 PRINT "V TERMINAL";V_terminal
860     Emf=V_terminal      !(V)
870     !
880     !Convert Emf to temperature (C) for type E TC.
890     !
900     V=Emf*1000.        !(mV)
910     PRINT "V=" ;V,"mV"
920     T=1.7022525E+1*V-2.2097240E-1*V*V+5.4809314E-3*V^3-5.7669892E-5*V^4.0
930 ! (C) PRINT "T Terminal =" ;T,"(C)"
940     !
950     ! 3. Convert Type-T TC voltage to temperature (C).
960     !
970     !     a. Find the Emf(mV) corresponding to a given temperature.
980     !
990     Emf=3.8740773840E+1*T+3.3190198092E-2*T^2+2.0714183645E-4*T^3-2.19458348
1000 23E-6*T^4.
1010     Emf=Emf+1.1031900550E-8*T^5-3.0927581898E-11*T^6+4.5653337165E-14*T^7.
1020     Emf=Emf-2.7616878040E-17*T^8.
1030     Emf=Emf*.001
1040     !
1050     !     a. Find the EMF for a Type-T TC for the terminal strip temperature.
1060     !
1070     Emf_correct=Emf
1080     !
1090     FOR K=1 TO I_finish
1100         FOR J=1 TO 6
1110             Emf=Emf_correct+Data(K,J)*1000.-Bias_voltage
1120             !Convert Emf(V) to temperature(C) for type T TC.
1130             !
1140             V=Emf
1150             T=2.5661297E+1*V-6.1954869E-1*V*V+2.2181644E-2*V^3-3.550090E-4*V^4.

```

```

1160         Data(K,J)=T
1170     NEXT J
1180 NEXT K
1190!
1200! 4. Correct remaining lines for Type-E TC bias.
1210 !SET FLAG FOR VOLTS FROM POT (J=7) TO X DISTANCE
1220 Flag=0
1230!
1240     FOR K=1 TO I_finish
1250         FOR J=7 TO 9
1260             Data(K,J)=Data(K,J)-Bias_voltage/1000
1270             IF J=7 THEN
1280                 Data(K,J)=3.022260*Data(K,J)+.00227 !VOLTAGE TO DISTANCE
1290             IF Flag=0 THEN
1300                 Initial_x=Data(1,7)
1310             END IF
1320             Flag=1
1330             Data(K,J)=(Data(K,J)-Initial_x)*2.54 !X IN CENTIMETERS
1340             END IF
1350             IF J=8 THEN
1360                 Data(K,J)=Data(K,J)/2. !I=V/R R=20HMS .
1370             END IF
1380             IF J=9 THEN
1390                 Data(K,J)=Data(K,J)*Data(K,8) !P=V*I
1400             END IF
1410         NEXT J
1420     NEXT K
1430!
1440!
1450! C. Now print out all the data and write to disk.
1460!PRINTER IS 701
1470!
1480 !PRINT !SPACE LINE
1490!
1500 FOR K=1 TO I_finish
1510     PRINTER IS 1
1520     PRINT "LOOP";K
1530     FOR J=1 TO 9
1540         OUTPUT @File;Data(K,J)
1550         PRINT "CH";J,"=";Data(K,J)
1560     NEXT J
1570 NEXT K
1580 PRINTER IS 701
1590 PRINT " FLUID TEMP AT START IS = ";Data(1,6),"C"
1600 PRINT " FLUID TEMP AT END IS = ";Data(I_finish,6),"C"
1610 PRINT
1620 ASSIGN @File TO File_name$ !close the file descriptor.
1630 !
1640 !
1650 PRINTER IS 1
1660 BEEP
1670 PRINT File_name$;" is written and closed."
1680 END

```

```

10      !      PROGRAM "SEND_DATA"
20      !
30      !      To VAX,IBM,TRS-80.
40      !
50      !      HP-9826 TERMINAL PROGRAM
60      !      [REQUIRES BINARY ENHANCEMENT PROGRAM
70      !      "BEB"! ]
80      !
90      !      JUNE 30, 1982
100     !      updated 1/5/83
110     !      updated 1/16/84
120     !
130     !      BILL CULBRETH
140     !
150     !
160     Sc=9      ! RS-232 IS SELECT CODE 9.
170     PRINTER IS 1 ! PRINTER IS CRT.
180     Pr=1      ! DEFAULT PRINTER IS CRT
190     Printer_choice=701 ! MY PRINTER IS 701.
200     Bits=7    ! BITS PER CHARACTER
210     Duplex=0   ! FULL DUPLEX
220     Baud=300   ! BAUD RATE
230     Computer=1 ! ASSUME IBM COMPUTER
240     !
250     OUTPUT Pr;"(300 BAUD. IBM assumed."
260     OUTPUT Pr;" Load the binary program BEB first"
270     OUTPUT Pr;" unless you have BASIC 2.0"
280     OUTPUT Pr;" SET MODEM ON <FULL DUPLEX> }"
290     OUTPUT Pr;" "
300     !
310     DIM Name$(200),Hp_file$(30),Aa(1500),Numb$(30)
320     INTEGER Isend
330     !
340     CONTROL Sc,3:Baud
350     CONTROL Sc,4:Bits-5+4 ! BITS/CHAR & #STOP BITS.
360     !
370     !
380     To_disk=0
390     Datadump=0
400     I_data=1
410     I=1
420     J=1
430     K=1
440     L=1
450     !
460     ON ERROR GOTO Errors
470     ON KEY 0 LABEL "Line Mode" GOTO Line_mode
480     ON KEY 5 LABEL "Terminal" GOTO Terminal
490     ON KEY 6 LABEL "To Crt" GOTO Pr_crt
500     ON KEY 7 LABEL "To Prt" GOTO Pr_prt
510     ON KEY 8 LABEL "DATA" GOTO Data_dump
520     !
530     !
540     Line_mode:      !
550         OUTPUT Pr;"(LINE RECEPTION MODE)"
560     Begin: STATUS Sc,10:Y ! CHECK FOR FULL BUFFER
570*
580         IF BIT(Y,0)=0 THEN GOTO Begin
590     !

```

```

600 ! RECEIVE ROUTINE.
610 !
620 Receive: STATUS Sc,6:A
630 B=A
640 OUTPUT Pr USING "#,A";CHR$(B)
650 IF B=63 AND Datadump=1 THEN GOTO Data_dump
660 IF B=13 AND Computer=3 THEN OUTPUT Pr;CHR$(13)
670 GOTO Begin
680 !
690 ! TRANSMIT ROUTINE.
700 !
710*
720 IF Duplex=0 THEN
730 IF NUM(Key$)<>255 THEN OUTPUT Pr USING "#,A";Key$
740 IF NUM(Key$)=255 THEN OUTPUT Pr;" "
750 END IF
760 IF Computer=1 AND NUM(Key$)=8 THEN Key$=CHR$(64)
770 !
780 ! the previous line gives an @
790 ! for a backspace for the IBM.
800 !
810 IF Computer=5 AND NUM(Key$)=8 THEN Key$=CHR$(127)
820 !
830 ! THE VAX/VMS REQUIRES A DELETE
840 ! SYMBOL FOR A BACKSPACE.
850 !
860 IF NUM(Key$)=255 THEN Key$=CHR$(13)
870 OUTPUT Sc USING "#,A";Key$
880 GOTO Begin
890 !
900 !
910 !
920 ! DATA FILE OUT TO THE HOST COMPUTER.
930 !
940 !
950 !
960 Data_dump: !
970 IF I_data=1 THEN GOSUB Open_file
980 !
990 IF Datadump=0 THEN GOTO Begin
1000 IF Computer=1 THEN WAIT .3
1010 ! wait for the slow IBM.
1020 BEEP 1000+RND*1500..05
1030 OUTPUT Pr;"A(";I_data:")=";
1040 OUTPUT Pr:Aa(I_data)
1050 GOSUB Send_number
1060 IF Aa(I_data)=-200 THEN
1070 I_data=1
1080 Datadump=0
1090 END IF
1100 I_data=I_data+1
1110 GOTO Begin
1120 !
1130 !
1140 ! ERROR HANDLING SUBROUTINE
1150 !
1160 Errors: OFF ERROR
1170 Close_file=-200
1180 ! FIRST, END OF FILE ERROR.
1190 IF ERRN=59 THEN
1200 Aa(I)=-200

```

```

1210          GOTO 2000 ! RETURN AFTER ERROR.
1220      END IF
1230      !
1240      IF ERRN<>59 THEN OUTPUT Pr;"<error #":ERRN;" generated.>"
1250      IF ERRN=54 THEN OUTPUT Pr;"(FILE <";Hp_file$;"> ALREADY THERE)"
1260      IF ERRN=54 THEN GOTO Created
1270      IF ERRN=56 THEN OUTPUT Pr;"<FILE <";Hp_file$;" IS NOT ON DISK.>"
1280      ASSIGN @File TO *
1290  GOTO Line_mode
1300      !
1310      !
1320      ! OUTPUT TO CRT.
1330      !
1340  Pr_crt:  Pr=1
1350          GOTO Line_mode
1360      !
1370      !
1380      ! OUTPUT TO PRINTER.
1390      !
1400  Pr_prt:  Pr=Printer_choice
1410  GOTO Line_mode
1420      !
1430      !
1440      ! CHANGE THE TERMINAL CHARACTERISTICS.
1450      !
1460  Terminal:  !
1470          OUTPUT Pr;"          1.  Baud Rate =":Baud
1480          OUTPUT Pr;"          2.  Bits/Char =":Bits
1490          OUTPUT Pr;"          3.  Duplex   =":Duplex
1500          OUTPUT Pr;"          [1=full,0=half]"
1510          OUTPUT Pr;"          4.  Computer =":Computer
1520          OUTPUT Pr;"          [IBM=1, VAX/UNIX=2, "
1530          OUTPUT Pr;"          TRS-80=3, Cyber=4, vax/vms=5]"
1540          OUTPUT Pr;" "
1550          INPUT "Change which one?",Which
1560          IF Which=1 THEN INPUT "To?",Baud
1570          IF Which=2 THEN INPUT "To?",Bits
1580          IF Which=3 THEN INPUT "To?",Duplex
1590          IF Which=4 THEN INPUT "To?",Computer
1600          IF Computer=1 THEN Duplex=0
1610          IF Computer=3 THEN Duplex=0
1620          IF Computer=3 THEN Bits=8
1630          IF Computer=5 THEN Duplex=1
1640  GOTO Line_mode
1650      !
1660      !
1670      !
1680  Open_file:  !
1690              ! Open a file to read data from
1700              ! disk,
1710              !
1720      Datadump=1
1730      !
1740      INPUT "Is this LDV data? (1=YES)",Ldv$
1750      IF Ldv$="1" THEN
1760          INPUT "Experiment #?",Experiment$
1770      ELSE
1780          OUTPUT Pr;"Data file out of HP to host."
1790          INPUT "File name?",Hp_file$
1800      END IF

```

```

1810      !
1820      IF Ldv$="1" THEN
1830          Hp_file$=Experiment$a"_RESULT"
1840      END IF
1850      !
1860      !   Read the file off of disk.
1870      !
1880      ASSIGN @File TO Hp_file$
1890      I=1
1900      Check=0
1910      BEEP
1920      BEEP
1930      OUTPUT Pr;"(Working on file <":Hp_file$;">.)"
1940      !
1950*
1960          ENTER @File:Aa(I)
1970          Check=Aa(I)
1980          I=I+1
1990*
2000      !
2010      .  ASSIGN @File TO *
2020          Datadump=1
2030      RETURN
2040      !
2050      !
2060      !
2070      Send_number: !
2080          ! SEND A NUMBER ONE CHARACTER AT
2090          ! A TIME TO THE HOST COMPUTER.
2100          !
2110          Numb$=VAL$(Aa(I_data))
2120          Length=LEN(Numb$)
2130          !
2140          IF ((Ldv$="1") AND (I_data>13)) THEN
2150              Posit=PDS(Numb$,".")
2160              IF (Posit<>0) THEN Length=Posit+2
2170          END IF
2180          !
2190          FOR I=1 TO Length
2200              Numeric=NUM(Numb$[I,I])
2210              OUTPUT Sc USING "#,A";Numb$[I,I]
2220          NEXT I
2230          !
2240          OUTPUT Sc USING "#,A";CHR$(13)
2250      RETURN
2260      !
2270      !
2280      !
2290      END

```

APPENDIX C

FORTRAN PROGRAMS USED ON THE IBM 3033

FILE: GRAB FORTRAN A1

```

C      PROGRAM GRAB
C
C      TEST PROGRAM FOR DATA TRANSFER FROM THE HP-9826
C      TO THE IBM.
C
C      BY BILL CULERETH
C      FOR ME2410, FALL QUARTER, 1982
C
C      FILEDEF 05 TERMINAL
C      FILEDEF 06 TERMINAL
C      FILEDEF 07 DISK MYDATA DATA (PERM)
C
C      GLOBAL TXTLIB FORTMCD2 MCD2EEH
C
C      TYPE IN THE ABOVE 4 LINES TO MAKE THIS
C      FORTRAN PROGRAM RUN.
C
C      DIMENSION DATA(3000)
C      I=1
C      WRITE(6,80)
80    FORMAT(2X,'BEGIN INPUTING DATA FROM THE HP-9826')
C
C      10    CONTINUE
C      READ(5,*) DATA(I)
C      I=I+1
C      IF(DATA(I-1).NE.-200) GOTO 10
C
C      NITEMS = I-1
C      6      FORMAT(2X,I5,' DATA POINTS WERE ENTERED.')
C      WRITE(6,6) NITEMS
C
C      NOW THAT ALL DATA HAS BEEN ENTERED, WRITE IT OUT ON
C      DISK.
C
C      5      FORMAT(2X,'DATA(*,I5,*) = *,I5I5.5)
C      I=1
C      20    WRITE(7,*) DATA(I)
C      I=I+1
C      IF(DATA(I-1).NE.-200) GOTO 20
C
C      ALL DATA HAS BEEN WRITTEN ONTO DISK.
C
C      STOP
C      END

```

FILE: WATARRING.FORTRAN 84

```
C      PROGRAM REARRANGE
C
C      BY BILL CULBRETH
C      22 JUNE 1984
C      NAVAL POSTGRADUATE SCHOOL
C      REVISED BY R. WATSON 1 SEP 84 TO HANDLE 9 CHANNELS OF DATA
C
C      PURPOSE: TAKE IN DATA ACQUIRED ON THE HP-9826 AND PLACE IT
C               IN ORDERED ARRAYS.
C
C      FILEDEF 20 == INPUT
C      FILEDEF 21 == OUTPUT
C
C      DIMENSION X(1000),Y(1000),Z(1000),A(1000),B(1000),C(1000),
C      * D(1000),E(1000),F(1000),G(1000)
C      I=1
100  CONTINUE
      READ(20,*) X(I)
      CHECK=X(I)
      IF(CHECK.EQ.-200.0) GOTO 5
      READ(20,*) Y(I)
      READ(20,*) Z(I)
      READ(20,*) A(I)
      READ(20,*) B(I)
      READ(20,*) C(I)
      READ(20,*) D(I)
      READ(20,*) E(I)
      READ(20,*) F(I)
      I=I+1
      GOTO 100
5    CONTINUE
      NITEMS = I-2
      WRITE(5,*) NITEMS
      WRITE(21,*) NITEMS
C
C      WRITE ALL DATA TO A DISK FILE.
C
C      DO 91 I=1,NITEMS
C      * MULTIPLY E(I) TIMES F(I) = CURRENT *VOLTAGE = POWER
C      * G(I)=E(I)*F(I)
C
C      WRITE(21,*) X(I),Y(I),Z(I),A(I),B(I),C(I),D(I),E(I),F(I)
C      * WRITE(5,10) I,X(I),Y(I),Z(I),A(I),B(I),C(I),D(I),E(I),F(I)
C      * FORMAT (15,9(1X,F0.2))
10  CONTINUE
91  CONTINUE
C
C      STOP
C      END
```

FILE: SMA3 FORTA.M 311

```

C PROGRAM BY LT. R. WATSON, SEPTEMBER 10, 1984
C THE PURPOSE OF THE PROGRAM IS CONTRAST TEMPERATURE AND
C DISPLACEMENT OF A SMA COIL AS IT RECOVERS UNDER THE APPLIED
C POWER. DATA WAS OBTAINED FROM THE DATA ACQUISITION SYSTEM OF
C THE SHAPE MEMORY ALLOY TESTING SYSTEM, CONSTRUCTED BY
C LT. WATSON.
C THIS PROGRAM WILL PLOT DATA FROM 2 FILES SIDE BY SIDE.
C TWO GRAPHS FOR EACH FILE ARE PLOT ONE UNDER THE OTHER.
C CURRENTLY, THE TOP LEVEL GRAPHS PLOT TEMPERATURE OF THE
C SMA COIL AT ITS TWO ENDS AND MIDPOINT. THE BOTTOM GRAPHS
C PLOT CURRENT AND POWER APPLIED DURING THE PARTICULAR TEST RUN
C AND THE RECOVERY DISPLACEMENT OF THE COIL AS A FUNCTION OF TIME.
C *****
C DATA FILE DIMENSION VARIABLE *****
C
C      X      Y      Z      A      B      C      D      E      F
C      A      B      C      D      E      F      G      H      I
C      J      K      L      M      N      O      P      Q      R
C      S      T      U      V      W      X      Y      Z      AA
C *****
C      DIMENSION X(100),Y(100),Z(100),A(100),B(100),C(100),
C      * D(100),E(100),F(100),G(100),H(100),I(100),J(100),K(100),L(100),M(100),N(100),O(100),P(100),Q(100),R(100),S(100),T(100),U(100),V(100),W(100),X(100),Y(100),Z(100),AA(100)
C READ DATA INTO THE ARRAYS
C      NDATA=2
C      XPHYS=50
C      CALL GCHPFS
C      CALL TEK613
C      CALL PAGE(14.0,10.0)
C      CALL HLOOKUP(1.00)
C      CALL HWRDOR
C      DO 99 ISET=1,NDATA
C      IF (ISET.EQ.2) GO TO 45
C      READ(31,*) NITEMS
C      DO 51 I=1,NITEMS
C      READ(21,*) X(I),Y(I),Z(I),A(I),B(I),C(I),D(I),E(I),F(I),
C      * G(I),H(I),I(I),J(I),K(I),L(I),M(I),N(I),O(I),P(I),Q(I),
C      * R(I),S(I),T(I),U(I),V(I),W(I),X(I),Y(I),Z(I),AA(I)
C      51 CONTINUE
C      REWIND 21
C      GO TO 52
C      45 CONTINUE
C      READ(22,*) NITEMS
C      DO 52 I=1,NITEMS
C      READ(22,*) X(I),Y(I),Z(I),A(I),B(I),C(I),D(I),E(I),F(I),
C      * G(I),H(I),I(I),J(I),K(I),L(I),M(I),N(I),O(I),P(I),Q(I),
C      * R(I),S(I),T(I),U(I),V(I),W(I),X(I),Y(I),Z(I),AA(I)
C      52 CONTINUE
C      DO 92 K=1,NITEMS
C      92 T(K)=FLOAT(K)*2.075
C      TMAX=FLOAT(NITEMS)
C      LEVEL 1
C      CALL PHYSOR(XPHYS,5.5)
C      CALL APLAZO(14.0,3.0)
C      CALL XNAME('TIME (SEC)',1,100)
C      CALL YNAME('TEMPERATURE',1,100)
C      CALL INTAXS
C      CALL GRAF(0.0,30,10.0,20.0,10,125.)
C      CALL DOT
C      CALL GRID(04,C1)
C      CALL RESET('ECT')
C PLOT TEMPS
C      CALL THKCPV(.01)
C      CALL CURVE(T,X,NITEMS,0)
C      CALL CHNDOT
C      CALL CURVE(T,Z,NITEMS,0)
C      CALL CHNDOT
C      CALL CURVE(T,A,NITEMS,0)
C      CALL DASH
C      CALL CURVE(T,B,NITEMS,0)
C      CALL THKFR1(.015)

```

FILE: SMA3 FORTRAN A1

```

CALL FRAME
CALL COMPLX
C
IF (ISST.EQ.2) GO TO 998
CALL HEADIN('RUN 198$ ', -100, -1.25, 4)
CALL HEADIN('I = 1.25 AMPS, LOAD = 1.3 N5', 100, 1., 4)
CALL HEADIN('COOLED IN CHAMBER, NO WATERS', -100, .75, 4)
GO TO 999
998 CONTINUE
CALL HEADIN('RUN 198$ ', -100, -1.25, 4)
CALL HEADIN('I = 2.0 AMPS, LOAD = 1.3 N5', 100, 1., 4)
CALL HEADIN('COOLED IN AIR$', -100, .75, 4)
999 CONTINUE
C
CALL HEADIN('COIL AND AMBIENT TEMPS VS. TIMES', 100,
* 1., 4)
C
C SET UP LEGEND FOR THE SECOND CALL
IF (ISST.EQ.1) GO TO 888
CALL HEIGHT (.12)
MAXLIN=LINESY(TEMPAK,500,33)
CALL LINES(' T2 AMBIENT$',TEMPAK,1)
CALL LINES(' T3 AT COIL BEGINS',TEMPAK,2)
CALL LINES(' T4 AT COIL CENTER$',TEMPAK,3)
CALL LINES(' T5 AT COIL ENDS',TEMPAK,4)
CALL LSTORY(TEMPAK,4,4.75,2.5)
C
888 CONTINUE
CALL RESET(3HALL)
CALL ENDGR(0)
C PLCT VOLT, LOGS
CALL PHYSO(XPHYS,1.)
CALL AREA2D(4,C,3.0)
CALL ANAME('TIME (SEC)',100)
CALL YNAME('I (AMPS) & P (W) & X (CM)',100)
CALL INTAXS
CALL GRAF(0,0,20,210.,-1.0,1.,9.)
CALL CURVE(T,C,NITEMS,0)
CALL RESET('CHNDCT')
CALL CHNDCT
CALL CURVE(T,E,NITEMS,0)
CALL DASH
CALL CURVE(T,F,NITEMS,0)
C
CALL CURVE(T,G,NITEMS,0)
CALL RES-T(3HALL)
CALL COMPLX
CALL THNFRM(.015)
CALL FRAME
CALL HEADIN('POWER, CURRENT, AND DISPLMT VS. TIMES',
* 100, 1., 1)
C
C SET UP LEGEND FOR SECOND CALL
IF (ISST.EQ.1) GO TO 889
CALL HEIGHT (.12)
MAXLIN=LINESY(POWPAK,500,33)
CALL LINES(' COIL DISPLACEMENT$',POWPAK,1)
CALL LINES(' CURRENT THRU COIL$',POWPAK,2)
CALL LINES(' POWER TO COIL$',POWPAK,3)
CALL LSTORY(POWPAK,3,4.75,2.5)
889 CONTINUE
C
CALL RESET('COMPLEX')
CALL ENDGR(0)
XPHYS=XPHYS+5.5
99 CONTINUE
CALL ENOPL(0)
CALL DONEPL
STOP
END

```

FILE: LOGGRAPH FORTRAN

```

C LOGGRAPH, WRITTEN BY D. WATSON, 10 OCT 84
C THIS PROGRAM USES INPUT FROM PROGRAM POLYFIT TO PLOT
C THE LOG OF NORMALIZED DISPLACEMENT OF THE SURFACE COIL AS
C IT IS COOLED. THE INPUT OF THE FILE IS TO DETERMINE THE COOLING
C TIME CONSTANT OF THE COIL UNDER VARIOUS COOLING CONDITIONS.
C THIS PROGRAM PLOTS DATA FROM 3 DIFFERENT FILES CORRESPONDING
C TO THREE DIFFERENT COOLING CONDITIONS.
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   DIMENSION X(100),Y(100),Z(100),A(5),ABAB(100),
C   * XX(100),YY(100),ZZ(100),AA(5),ABABA(100),
C   * XXX(100),YYY(100),ZZZ(100),AAA(5),ABABB(100),
C   * LLGPAK(1000),IPAK(1000)
C   COMMON /DY(100)
C   INTEGER K,N4,NN4,I,J
C
C   SET UP THE TEK GRAPHICS SCREEN FOR PLOTTING
C   CALL COMPTS
C   CALL TEK613
C   CALL PRTPLOT(72,6)
C   CALL BLKWUP(11,2)
C   CALL HWSCT(1000,1)
C   CALL HWSCL(1000,1)
C   TEK613 SCREEN DIMENSIONS (14.0,10.5)
C   CALL PAGE(14.0,11.)
C   CALL NBSFOR
C   CALL INSET('ALL')
C   CALL GRACE(0.00)
C
C   DATA IS FROM THREE POLYFIT CREATED DATA FILES INTO THE ARRAYS
C   X IS TIME, Y IS NORMALIZED DISPLACEMENT OF ORIGINAL DATA FILE
C   Z IS DATA FROM POLYFIT LEAST SQUARES 1ST ORDER CURVE FIT
C
C   NOW READ THE DATA INTO ARRAYS.
C   THE FIRST TWO NUMBERS ARE THE COEFFICIENTS OF THE LEAST SQUARES
C   FIT. 1 IS THE Y INTERCEPT. 2 IS THE SLOPE. 1/SLOPE IS THE TIME
C   CONSTANT OF THE SYSTEM.
C
C   FIRST FILE
C   IJUNK=2
C   DO 92 I=1,IJUNK
C     READ(21,*) L,A(1)
C     WRITE(6,*) L,A(1)
C 92 CONTINUE
C
C   READ(21,*) N
C
C   DO 93 J=1,N
C     READ(21,*) X(J),Y(J),Z(J),ABAB(J)
C     WRITE(6,*) X(J),Y(J),Z(J),ABAB(J)
C 93 CONTINUE
C
C   SECOND FILE
C   DO 94 I=1,IJUNK
C     READ(22,*) LL,AA(1)
C     WRITE(6,*) LL,AA(1)
C 94 CONTINUE
C
C   READ(22,*) NN
C
C   DO 95 J=1,NN
C     READ(22,*) XX(J),YY(J),ZZ(J),ABABA(J)
C     WRITE(6,*) XX(J),YY(J),ZZ(J),ABABA(J)
C 95 CONTINUE
C
C   THIRD FILE
C   DO 96 I=1,IJUNK
C     READ(23,*) LLL,AAA(1)
C     WRITE(6,*) LLL,AAA(1)
C 96 CONTINUE
C
C   READ(23,*) NNN

```

FILE: LOGGRAPH FORTRAN -1

```

C
DO 97 J=1,NIN
  READ(25,*) XXX(J),YYY(J),ZZZ(J),ABAB(J)
  WRITE(6,*) XXX(J),YYY(J),ZZZ(J),ABAB(J)
C 97 CONTINUE
C
CALL PHYSCP(0.75,0.00)
CALL AREAD(3.0,0.0)
CALL THKFE1(0.015)
CALL SP_LVE
CALL COMFLX
C
CALL INTXSS
C
CALL HEADIN('LOG OF NORMALIZED SMA COIL DISPLACEMENT VS TIMES',
* -100,-1.25,4)
CALL HEADIN('SMA EXTENSION DISPLACEMENT AFTER RECOVERYS',
* -100,1.15,4)
CALL HEADIN('THREE COOLING CONDITIONS AFTER SMA RECOVERYS',
* 100,1.,4)
CALL HEADIN('WATER, NATURAL AIR CONVECTION, CHAMBER=NO COOLANTS',
* 100,1.,4)
C
CALL RESET('COMPLEX')
CALL XTIME('TIME (SEC)',100)
CALL YTIME('LN(EXT/RECOV)',100)
CALL SRAFC(0.0,20.,150.,-1.0,-.10,-0.0)
CALL THKCFV(0.01)
C
PLOT FILE NUMBER ONE
C PLOT LOG (DISPLMT) OF ORIGINAL DATA AS INDIVIDUAL DATA POINTS
CALL MARKER (1)
CALL LEGLIN
CALL CURVE (X,Y,N,-1)
C
PLOT LEAST SQUARES DATA AS SMOOTH LINE
CALL LEGLIN
CALL CURVE (X,Z,N,0)
C
PLOT FILE NUMBER TWO
C PLOT LOG (DISPLMT) OF ORIGINAL DATA AS INDIVIDUAL DATA POINTS
CALL MARKER (3)
CALL LEGLIN
CALL CURVE (XX,YY,NN,-1)
C
PLOT LEAST SQUARES DATA AS SMOOTH LINE
CALL CHNDCT
CALL LEGLIN
CALL CURVE (XX,ZZ,NN,0)
C
PLOT FILE NUMBER THREE
C PLOT LOG (DISPLMT) OF ORIGINAL DATA AS INDIVIDUAL DATA POINTS
CALL MARKER (5)
CALL LEGLIN
CALL CURVE (XXX,YYY,NNN,-1)
C
PLOT LEAST SQUARES DATA AS SMOOTH LINE
CALL CHNDCT
CALL LEGLIN
CALL CURVE (XXX,ZZZ,NNN,0)
C
CALL DOT
CALL BLNK1 (5.20,7.00,.800,1.6,1)
CALL DOT
CALL GRID(05,02)
CALL RESET('DOT')
CALL RESET('BLNK1')
C
SET UP LEGEND
CALL LINESP (2.0)
CALL HEIGHT (.11)
MAXLIN=LINEST (LEGPAN,500,40)

```

FILE: LCGRPH.FOR 1

```

CALL LINES(' = ORIGINAL DATA, COOLING IN CHAMBER$',LEGPAK,1)
CALL LINES(' = LEAST SQ. FIT, COOLING IN CHAMBER$',LEGPAK,2)
CALL LINES(' = ORIGINAL DATA, AIR COOLING$',LEGPAK,3)
CALL LINES(' = LEAST SQ. FIT, AIR COOLING$',LEGPAK,4)
CALL LINES(' = ORIGINAL DATA, WATER COOLING$',LEGPAK,5)
CALL LINES(' = LEAST SQ. FIT, WATER COOLING$',LEGPAK,6)
C
CALL LEGEND(LEGPAK,8,8.5,6)
C
CALL HEIGHT(.12)
MAXLIN=LINES(IPAK,500,50)
CALL LINES('COOLING OF THE SMA COIL IS ACCORDING$',IPAK,1)
CALL LINES(' TO THE EXPONENTIAL RELATIONSHIP:$',IPAK,2)
CALL LINES('$',IPAK,3)
CALL LINES('$',IPAK,4)
CALL LINES(' IS THE TIME CONSTANT OF THE$',IPAK,5)
CALL LINES(' COOLING SMA COIL. ON THE NATLOG PLOTS$',IPAK,6)
CALL LINES(' FOR CH. B. LEADS AS = /SLOP. (SEC).$',IPAK,7)
CALL LINES(' FOR THE THREE SYSTEMS; RUNS 81, 85, & 194$',IPAK,8)
CALL LINES('$',IPAK,9)
CALL LINES(' = 165.664 SEC, CHAMBER-NO COOLANT$',IPAK,10)
CALL LINES(' = 161.638 SEC, NATURAL AIR CONVECTION$',IPAK,11)
CALL LINES(' = 11.007 SEC, WATER COOLED$',IPAK,12)
C
CALL LINES('1.3 IN$',IPAK,9)
CALL LSTORY(IPAK,12,8.5,3.1)
C
CALL ENDOR(0)
CALL SUMOPL(0)
CALL SUMTPL
STOP
END

```

FILE: TEMGRPH FORTRAN 01

```

C PROGRAM TEMGRPH, WRITTEN BY B. WATSON, 10 OCT 1984.
C WRITTEN FOR USE ON THE IBM 3033.
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C THIS PROGRAM PLOTS FLUX DISPLACEMENT OF THE SMA COIL
C DURING A COMPLETE RUN VS. THE TEMPERATURE IN THE CENTER OF THE COIL.
C DATA FILES FROM THE SMA DATA ACQUISITION SYSTEM WHICH HAVE BEEN
C TRANSFERRED TO THE IBM 3033 ARE READ IN THIS PROGRAM.
C THE DISPLACEMENT, ARRAY U, AND TEMPERATURE ARRAYS, Z, E, & C ARE USED
C THE PURPOSE OF THE PLOT IS TO SHOW THE TEMPERATURE DEPENDENCE OF THE
C SMA COIL ACTUATION.
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C DIMENSION X(100),Y(100),Z(100),A(100),B(100),C(100),IPAK(500),
C * D(100),F(100),F(100),T(100),LEGPAK(500),COMMON(2000),FF(100),
C * ZZ(100),AA(100),BB(100),CC(100),DD(100),XX(100),YY(100),TH(100)
C INTEGER NITEM,NITEM,I
C CALL FMS618
C CALL COMPRE
C CALL PRTPLOT(72,0)
C CALL HWRECT('CEVIC')
C CALL HWSCL('DOWN')
C TEK615 SCFEE, DIVISIONS (14.0,10.5)
C CALL PAGE(14.0,10.5)
C CALL ALXLP(.75)
C CALL HURP
C CALL GRACE(0.00)
C READ DATA FROM BDAT FILES INTO THE ARRAYS USED FOR PLOTTING.
C ARRAY Z IS DISPLACEMENT OF SMA COIL.
C ARRAY T IS TIME OF RUN.
C
C READ(21,*) NITEM
C DO 52 I=1,NITEM
C READ(21,*) Z(I),Y(I),Z(I),A(I),B(I),C(I),D(I),E(I),F(I)
C T(I)=FLCAT(I-1)*2.075
52 CONTINUE
C READ(22,*) NNITEM
C DO 53 I=1,NNITEM
C READ(22,*) XX(I),YY(I),ZZ(I),AA(I),BB(I),CC(I),
C * DD(I),EL(I),FF(I)
53 CONTINUE
C SET UP GRAPH AREA AND HEADINGS
C CALL PHYSUN(3.75,0.80)
C CALL AREA2D(3.0,6.0)
C CALL COMPLEX
C CALL HEADIN('S',-100,-1.25,4)
C CALL HEADIN('I',100,1.4)
C CALL HEADIN('I',100,1.4)
C CALL HEADIN('SMA COIL DISPLACEMENT VS TEMPERATURE$',-100,1.1,1)
C CALL HEADIN('I',100,1.2)
C CALL RESET('COMPLEX')
C CALL XNAME('COIL TEMPERATURE (C)','$',100)
C CALL YNAME('DISPLACEMENT (CM)','$',100)
C CALL GRAF(20,5,80,0,0,1,10,0)
C CALL BLNK1(4.95,7.5,90,2.15,1)
C CALL DOT
C CALL GRID(02,02)
C CALL RESET('DOT')
C CALL RESET('ELNK1')
C CALL THKFRM(.017)
C CALL FRAME
C CALL THKCRV(.01)
C CALL SMOOTH
C
C PLOT DISPLACEMENT VS. TEMP OF FIRST FILE
C
C CALL CURVE(ZZ,DD,NITEM,0)
C CALL CURVE(AA,BB,NITEM,0)

```

FILE: TEMGPH FORTA .1

SET UP CURVE FROM SECOND FILE

CALL MARKER (4)
CALL LEGLIN
CALL CURVE (AA,DD,UNITE(1,3))

SET UP STORY

```
CALL TYPSET
CALL HIGHT ( .12 )
CALL MIXALE ('INSTRU')
MAXLE: I=LEINST(LEOFK,500,45)
```

[illegible]

SET UP LEGEND

```
CALL LINESP(2,2)
CALL H=HEIGHT(1,1)
MAXLX1:=LINESP(IPAK,500,50)
CALL LINESC('=DATA FROM RUN 851',
IPAK,1)
CALL LINESC('=DATA FROM RUN 010',
IPAK,2)
CALL LEGEND(IPAK,1,0.5,.7)
```

```
CALL ENDGR(0)
CALL ENDPL(0)
CALL DOREPL
STOP
END
```

APPENDIX D
CALIBRATION DATA

D.1 Potentiometer Calibration

The following relation was used in Basic program SMA to convert the 10 turn linear potentiometer voltage read by the HP 3497A to displacement:

$$X = 3.02260V + 0.0027$$

where X = SMA coil displacement from zero

V = potentiometer voltage output to the HP 3497A

D.2 Flow System Rotometer Calibration

The following relation converts the rotometer reading to volumetric flow rate:

$$M = 0.03419R + 1.6411$$

where M = volumetric flow rate through the system

R = the face plate reading on the rotometer

APPENDIX E DATA LISTINGS

BDAT files are to be read as follows:

Col.	1	2	3	4
row 1	T1	T2	T3	T4
row 2	T5	T6	Displacement	Current
row 3	Power			

LBDAT files are to be read as follows:

Col.	1	2	3	4
	Time	ln (normalized displacement)	Fitted Data Points	normalized displacement

FILE: BDAT81 DAT: A

99			
22.6096344	22.4866333	22.6834412	22.7572174
22.6834412	22.0189362	.0001	.300000011E-05
- .330000055E-10			
22.6096344	22.4620209	22.6588440	22.7572174
22.6834412	22.0435638	.153530855E-04	.300000011E-05
- .330000055E-10			
22.6096344	22.4620209	22.7326202	22.8063965
21.4768932	22.0189362	.383826991E-04	2.02335818
5.78984451			
22.6096344	22.4620209	24.0099640	24.8925018
23.4699249	22.0189362	.145854268E-03	2.02343845
5.76695538			
22.6096344	22.4620209	25.9936676	27.7264862
25.9203186	22.0139362	.256089382E-01	2.02333886
5.72432232			
22.5850372	22.4620209	23.1649170	30.7638397
28.6273193	22.0435638	.279955745	2.02358818
5.04455128			
22.6096344	22.4374237	30.2790070	33.6396942
32.6505737	22.0435638	.633805871	2.02333886
5.55213165			
22.5850372	22.4128113	32.2157593	36.3565674
35.4684601	22.0435638	1.19027805	2.02338886
5.47827816			
22.5850372	22.4128113	34.0733795	38.9167786
37.8893433	22.0681915	2.01596737	2.02343845
5.42620850			
22.5850372	22.4128113	35.5885620	41.5125885
40.3946059	22.0681915	3.64032269	2.02353859
5.38762474			
22.5850372	22.4128113	37.3385893	44.1907806
42.4146729	22.0189362	4.09830418	2.02353859
5.35970020			
22.5850372	22.3881989	38.7735291	46.7619017
43.9069777	22.0435638	5.03192463	2.02365870
5.34114455			
22.5850372	22.4374237	39.3469696	49.7426300
45.4896393	22.0681915	6.09566402	2.02353859
5.33146235			
22.5850372	22.4374237	40.8707275	52.5211334
47.1383209	21.9940237	6.51749039	2.02293813
5.05989730			
22.6096344	22.4374237	42.1062317	55.0565704
48.5710297	22.0189362	6.84435749	2.02336886
5.95195293			
22.6096344	22.4128113	43.4336053	59.0043370
50.2339630	22.0189362	7.07085083	2.02373845
5.04875221			
22.6096344	22.4128113	44.3760223	62.7630054
51.5887209	22.0435638	7.29758072	2.02383804
5.04727211			
22.6096344	22.4128113	46.3852386	66.6880951
53.1496277	22.0435638	7.40093750	2.02403886
5.37006233			
22.6096344	22.4374237	48.0312653	70.6491394
54.6133723	22.0435638	7.62836266	2.02243805
5.06723081			
22.6096344	22.4374237	49.6958160	74.4038391
56.0038757	22.0435638	7.75563908	2.02403831
5.40049267			
22.6096344	22.4620209	51.3787231	77.9734698
57.7602234	22.0435638	7.76968765	.195000000E-04
.208650008E-08			
22.5804401	22.4128113	52.3813782	79.3133240
57.9678497	22.0435638	7.76907349	.1300000061E-04
.104400000E-08			
22.5804401	22.4128113	52.7074280	79.5799255
57.6217651	22.0435638	7.76907349	.1750000023E-04
.980000031E-09			
22.5358429	22.4128113	52.5444336	79.1799774
56.9053380	22.0189362	7.76907349	.1750000023E-04

FILE: BDATA31 DATA A

.945000073E-09	22.4123113	52.1250610	78.3347321
22.5358429	22.0435638	7.76907349	.169999985E-04
56.0033757			
.832999891E-09	22.3881939	51.4720764	77.2429982
22.5112305	22.0435638	7.76914978	.164999947E-04
54.9845123			
.742500061E-09	22.3681939	50.7482300	75.9480896
22.5112305	22.0435638	7.76907349	.160000054E-04
53.8703766			
.655999921E-09	22.3881939	49.7532471	74.5830341
22.5112305	22.0435638	7.76914978	.164999947E-04
52.7772827			
.593999960E-09	22.4128113	49.1102753	73.0801036
22.4866333	22.0435638	7.76914978	.155000016E-04
51.6587219			
.511499954E-09	22.4128113	48.3129425	71.6132556
22.5358429	22.0189362	7.76922703	.155000016E-04
50.5846558			
.465000038E-09	22.4128113	47.4909608	70.1526794
22.5358429	21.9943237	7.76922703	.155000016E-04
49.5319214			
.418499931E-09	22.4128113	46.7148437	68.7059937
22.5358429	22.0189362	7.76930332	.155000016E-04
48.5006551			
.387500032E-09	22.4374237	45.7140472	67.3237152
22.5358429	22.0435638	7.76930332	.155000016E-04
47.5614624			
.340999895E-09	22.4123113	45.1593170	65.9153442
22.5358429	22.0435638	7.76930332	.149999996E-04
46.6442261			
.285000024E-09	22.4374237	44.4271698	64.5718637
22.5604401	22.0681915	7.76938057	.149999996E-04
45.7726135			
.285000024E-09	22.4374237	43.7413738	63.2937775
22.5604401	22.0928132	7.76523495	.149999996E-04
44.9468536			
.255000021E-09	22.4620209	43.0784302	62.0585937
22.5604401	22.0928132	7.74811649	.140000002E-04
44.1434937			
.223999999E-09	22.4620209	42.4384033	60.9124933
22.5850372	22.0681915	7.73475933	.140000002E-04
43.4100037			
.195999994E-09	22.4374237	41.8213654	59.7640536
22.5850372	22.0681915	7.69261551	.140000002E-04
42.6992493			
.181999998E-09	22.4620209	41.2511902	58.6824188
22.6096344	22.0435638	7.63450335	.140000002E-04
42.0350342			
.153999993E-09	22.4620209	40.7042034	57.6677230
22.6096344	22.0681915	7.53783054	.135000000E-04
41.3927836			
.148500004E-09	22.4866333	40.1304962	56.6515308
22.6588470	22.0681915	7.54392052	.135000000E-04
40.7517853			
.121500005E-09	22.4866333	39.6301300	55.7260437
22.6834412	22.0681915	7.48412037	.135000000E-04
40.1566772			
.107999998E-09	22.4866333	39.2031555	54.3453674
22.7080231	22.0189362	7.41618252	.135000000E-04
39.5609151			
.945000050E-09	22.4866333	38.7496490	54.0097656
22.7326202	22.0189362	7.35354233	.135000000E-04
38.9833881			
.809999934E-09	22.4866333	38.3196716	53.1961670
22.7326202	22.0435638	7.30518055	.135000000E-04
38.4391527			
.675000056E-10	22.4866333	37.9132538	52.4040783
22.7326202	22.0923192	7.24591732	.135000000E-04
37.8893433			
.675000056E-10	22.4866333	37.5005460	51.6353912
22.7572174	22.0435638	7.13097401	.135000000E-04
37.3629303			

FILE: 8DAT31 DATA A

.539999939E-10	22.4866333	37.1474457	50.9351136
22.7572174	22.0435638	7.12969398	.129999999E-04
36.8599854			
.389999977E-10	22.4620209	36.7641296	50.2339630
22.7572174	22.0435638	7.07112217	.129999999E-04
36.3325806			
.389999977E-10	22.4620209	36.4524841	49.5787506
22.7572174	22.0435638	7.00172615	.129999999E-04
35.8046722			
.259999938E-10	22.4620209	36.1166840	48.9462128
22.7572174	22.0681915	6.93424988	.129999999E-04
35.3483276			
.259999938E-10	22.4366333	35.8766937	48.3364105
22.7572174	22.0681915	6.37191582	.129999999E-04
34.8675090			
.130000004E-10	22.4620209	35.5885620	47.7494354
22.7572174	22.0681915	6.80735683	.124999997E-04
34.3863331			
.125000002E-10	22.4620209	35.3243103	47.1353485
22.7572174	22.0681915	6.75507927	.124999997E-04
33.9047699			
.125000002E-10	22.4366333	34.9637604	46.6205813
22.7326202	22.0681915	6.71661949	.124999997E-04
33.4709473			
.0			
22.7572174	22.4866333	34.6751404	46.1025848
33.0367889	22.0923192	6.65989017	.120000004E-04
-.120000000E-10			
22.7572174	22.4866333	34.3863831	45.5839844
32.6505737	22.0923192	6.59571457	.124999997E-04
-.125000002E-10			
22.7572174	22.4866333	34.0974579	45.1121063
32.2399139	22.0928192	6.50582218	.124999997E-04
-.125000002E-10			
22.7818146	22.4866333	33.8324890	44.6161957
31.8773193	22.0923192	6.49492168	.124999997E-04
-.125000002E-10			
22.7818146	22.4866333	33.5673823	44.1434937
31.5144806	22.0928192	6.45730591	.120000004E-04
-.120000000E-10			
22.7818146	22.4866333	33.3021545	43.7413788
31.1756134	22.0928192	6.42951679	.124999997E-04
-.125000002E-10			
22.7818146	22.4366333	33.0350572	43.2910107
30.8365326	22.1174316	6.36902013	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	32.8437195	42.8838702
30.5457133	22.0928192	6.32841682	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	32.5264191	42.4858398
30.2304993	22.0928192	6.29164600	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	32.4090576	42.0587616
29.9636383	22.0928192	6.25065327	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	32.2157593	41.7026215
29.6966400	22.0435638	6.20366299	.124999997E-04
-.250000021E-10			
22.7572174	22.4866333	31.9740448	41.3224945
29.4295044	22.0189362	6.15009117	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	31.7305939	40.9658601
29.2103459	22.0189362	6.06296253	.124999997E-04
-.250000021E-10			
22.7818146	22.4866333	31.5870667	40.6090240
28.9920959	22.0435638	6.00185680	.129999999E-04
-.389999977E-10			
22.8063965	22.4866333	31.3934784	40.2291139
28.7489471	22.0681915	5.94689274	.135000000E-04
-.269999995E-10			
22.7818146	22.4866333	31.2240295	39.3946223
28.5300140	22.0681915	5.90904608	.129999999E-04

FILE: BDA781 DATA A

- .389999977E-10	22.4620209	31.0303192	39.5370759
22.7313146	22.0681915	5.34594631	.124999999E-04
28.3353271			
- .259999938E-10	22.4620209	30.3607635	39.1792908
22.7313146	22.0928192	5.31915569	.124999999E-04
28.1405792			
- .130000004E-10	22.4620209	30.7153778	38.8451538
22.7326202	22.0681915	5.77332687	.124999999E-04
27.9457550			
- .130000004E-10	22.4620209	30.5457153	38.5103032
22.7572174	22.0681915	5.72872543	.135000000E-04
27.7752228			
- .134999997E-10	22.4866333	30.3760071	38.1762695
22.7572174	22.0928192	5.69103432	.124999999E-04
27.6046448			
- .130000004E-10	22.4866333	30.2304993	37.3654327
22.7572174	22.0928192	5.65280437	.124999999E-04
27.4340057			
- .130000004E-10	22.4866333	30.0849457	37.5304871
22.7572174	22.0139362	5.61710930	.124999999E-04
27.2633203			
- .130000004E-10	22.4620209	29.9393616	37.2192841
22.7326202	22.0681915	5.53335762	.124999999E-04
27.1169739			
0			
22.7080231	22.4374237	29.7937469	36.9073979
26.9705311	22.0928192	5.51562500	.124999999E-04
0			
22.6834+1E	22.4374237	29.6480713	36.5963440
26.8241577	22.0928192	5.48484230	.124999999E-04
0			
22.6834412	22.4374237	29.5023651	36.2846069
26.7021327	22.0928192	5.40285683	.124999999E-04
- .125000002E-10			
22.6834+1E	22.4374237	29.3809204	36.0205909
26.5556030	22.0139362	5.37975025	.124999999E-04
0			
22.6588440	22.4374237	29.2351379	35.7326355
26.4335022	22.0139362	5.35242176	.124999999E-04
0			
22.6834+1E	22.4620209	29.1379395	35.4444427
26.3113556	21.9943237	5.32064056	.124999999E-04
0			
22.7080231	22.4866333	29.0164032	35.1301147
26.2136230	22.0139362	5.25393200	.124999999E-04
0			
22.7080231	22.4366333	28.8948517	34.6915166
26.0914537	22.0435638	5.22345543	.124999999E-04
0			
22.7080231	22.4366333	28.7732697	34.6510925
25.9936676	22.0681915	5.16572357	.124999999E-04
- .125000002E-10			
22.7080231	22.4366333	28.6516413	34.3862831
25.8714294	22.0681915	5.12783296	.124999999E-04
- .125000002E-10			
22.7080231	22.4866333	28.5542335	34.1456299
25.7756053	22.0435638	5.07893331	.124999999E-04
- .125000002E-10			
22.7080231	22.4866333	28.4083405	33.8806763
25.7002411	22.0435638	5.05933189	.124999999E-04
0			
22.6834+1E	22.4620209	28.3353271	33.6396942
25.6024017	22.0681915	5.02240753	.124999999E-04
- .125000002E-10			
22.7080231	22.4374237	28.2136073	33.3936206
25.5045519	22.0681915	5.01319504	.124999999E-04
- .250000021E-10			
22.6834+1E	22.4374237	28.1162262	33.1574249
25.4311218	22.0928192	4.98636504	.124999999E-04
- .375000031E-10			
22.6588440	22.4374237	28.0188141	32.7402613
25.3577123	22.0681915	4.94249439	.124999999E-04

FILE: BDATA1 DAT: A

.250000021E-10	22.4374237	27.3970337	32.6983673
22.6588440	22.0928192	4.91309357	.129999999E-04
25.2842365			
.259999938E-10	22.4374237	27.3239594	32.5056763
22.6588440	22.0928192	4.35995125	.129999999E-04
25.2353210			
.259999938E-10	22.4374237	27.7264862	32.2882533
22.6342463	22.0928192	4.35563709	.124999997E-04
25.1618805			
.375000031E-10			

FILE: LBDAT81 DATA A

```
1 .185593265475650C93E-01
2 -.376387517155202250E-C2
65
.999999975E-05 .999999975E-05 .1855928455E-01 .999999975E-05
2.07499981 -.533782411E-03 .107492842E-01 .53358450E-03
4.14999962 -.274067768E-02 .293924473E-02 .273690745E-02
6.22499943 -.440611643E-02 -.437079471E-02 .445611030E-02
8.29999924 -.992961223E-02 -.126808323E-01 .988046050E-02
10.3749990 -.175125971E-01 -.204908736E-01 .173600949E-01
12.4499989 -.236447453E-01 -.283009149E-01 .233673714E-01
14.5249987 -.294484310E-01 -.361109562E-01 .290190503E-01
16.5999980 -.374069698E-01 -.439209677E-01 .367159508E-01
18.6749878 -.465260148E-01 -.517309941E-01 .454602577E-01
20.7499847 -.550082922E-01 -.595410243E-01 .535226936E-01
22.8249969 -.616067015E-01 -.673511028E-01 .597473644E-01
24.8999939 -.697522163E-01 -.751610994E-01 .673751235E-01
26.9749908 -.774755378E-01 -.829711556E-01 .757340193E-01
29.0499870 -.859221220E-01 -.907811522E-01 .823342800E-01
31.1249847 -.941712260E-01 -.985912085E-01 .898730755E-01
33.1999969 -.104033709E-01 -.106401265E-01 .988050699E-01
35.2749939 -.113717496E-01 -.114211321E-01 .107489944E-01
37.3499908 -.122747481E-01 -.122021377E-01 .115513027E-01
39.4249878 -.132186472E-01 -.129831374E-01 .123822391E-01
41.4999847 -.139895737E-01 -.137641430E-01 .130551100E-01
43.5749817 -.145605585E-01 -.145451427E-01 .135501266E-01
45.6499939 -.154087245E-01 -.153261542E-01 .142802894E-01
47.7249908 -.163770139E-01 -.161071539E-01 .151062965E-01
49.7999878 -.177492857E-01 -.168881595E-01 .162633061E-01
51.8749847 -.179169834E-01 -.176691592E-01 .164036095E-01
53.9499817 -.184976127E-01 -.184501648E-01 .168877602E-01
56.0249939 -.185290941E-01 -.192311704E-01 .172454357E-01
58.0999908 -.198743820E-01 -.200121760E-01 .180240154E-01
60.1749878 -.205140233E-01 -.207931817E-01 .185467005E-01
62.2499847 -.210967600E-01 -.215741813E-01 .190199733E-01
64.3249817 -.217504323E-01 -.223551369E-01 .195475936E-01
66.3999939 -.224444833E-01 -.231361926E-01 .200388052E-01
68.4749908 -.233723521E-01 -.239171932E-01 .208419323E-01
70.5499878 -.247991741E-01 -.246931978E-01 .219633698E-01
72.6249847 -.258121490E-01 -.254792035E-01 .227498651E-01
74.6999817 -.267321408E-01 -.262602031E-01 .234573065E-01
76.7749786 -.273705601E-01 -.270412087E-01 .239444077E-01
78.8499908 -.284441769E-01 -.273222144E-01 .247565925E-01
80.9249878 -.295035201E-01 -.280032200E-01 .251014173E-01
82.9999847 -.296941876E-01 -.293842256E-01 .256912827E-01
85.0749817 -.304697275E-01 -.301652253E-01 .262653470E-01
87.1499766 -.311298370E-01 -.309462209E-01 .267504752E-01
89.2249908 -.318038583E-01 -.317272365E-01 .272425294E-01
91.2999878 -.324373126E-01 -.325082421E-01 .277019620E-01
93.3749847 -.335395525E-01 -.332892418E-01 .287799353E-01
95.4499817 -.342605412E-01 -.340702474E-01 .290081739E-01
97.5249736 -.348202109E-01 -.348512471E-01 .294043779E-01
99.5999908 -.363262554E-01 -.356322587E-01 .304596186E-01
101.6749836 -.367548406E-01 -.364132583E-01 .307570219E-01
103.7499935 -.372641146E-01 -.371942639E-01 .311087668E-01
105.824942 -.378596723E-01 -.379752696E-01 .315178275E-01
107.899979 -.391213655E-01 -.387562592E-01 .323764324E-01
109.974976 -.397031188E-01 -.395372748E-01 .327686965E-01
112.049988 -.408144116E-01 -.403182805E-01 .335117042E-01
114.124985 -.415497601E-01 -.410992981E-01 .339988172E-01
116.199982 -.425079346E-01 -.418802357E-01 .346282065E-01
118.274979 -.428955913E-01 -.426612914E-01 .348811338E-01
120.349976 -.436280960E-01 -.434422910E-01 .353563964E-01
122.424988 -.436116908E-01 -.442233026E-01 .354719680E-01
124.499985 -.443382800E-01 -.450043023E-01 .358138621E-01
126.574982 -.452320213E-01 -.457853075E-01 .363849580E-01
128.649979 -.458280524E-01 -.465663075E-01 .367633760E-01
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132.799988 -.474177361E-01 -.481283247E-01 .377603233E-01
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FILE: BDATA2 DATA A

23.1331329	22.9364929	22.7643733	22.7643738
22.8135529	22.2230835	.0	-.30003001E-05
.300030025E-10	22.9364929	22.7643738	22.7643738
23.0839631	22.3461456	-.767654001E-05	-.249999994E-05
22.8135529	22.3461456	22.3135529	22.3381500
.250030021E-10	22.3461456	.767654001E-05	2.01884747
23.4279480	22.3461456	23.2559967	23.7716980
22.9456567	22.7151947	.460592419E-04	2.01869774
5.79711056	22.6627319	23.3296967	24.1397705
23.1085510	22.6660004	.460592419E-04	2.01879757
24.1642914	22.6660004	23.4033813	24.3850098
5.78517342	22.6660004	.537357846E-04	2.01879787
23.1085510	22.6660004	23.4033813	24.7036439
24.5811157	22.6660004	.307061564E-04	2.01914787
5.77052021	22.6660004	23.5507355	24.7771454
22.9364929	22.6660004	.230296232E-04	2.01869774
24.8751373	22.6660004	23.6244049	24.7771454
5.74710274	22.6660004	.153530855E-04	2.01869774
23.1085510	22.6660004	23.4770660	24.7281494
25.0955053	22.6660004	.767654001E-05	2.01954746
5.72489543	22.6660004	23.4525140	24.7036439
23.1331329	22.6660004	.153530855E-04	2.01914787
25.2669373	22.6660004	23.5016327	24.7281494
5.85470963	22.6660004	.153530855E-04	2.01914787
23.1331329	22.6660004	23.5753021	24.7771454
25.3403625	22.6660004	.767654001E-05	2.01914787
6.00157738	22.6660004	23.5016327	24.8261566
23.1085510	22.6660004	.230296232E-04	2.01939774
25.3843127	22.6660004	23.7716980	24.8751373
5.89540294	22.6660004	.153530855E-04	2.01944733
22.1085510	22.6660004	23.7716980	24.9480257
25.3640376	22.6660004	.153530855E-04	2.01939774
5.85234042	22.6660004	23.7226105	24.9731140
23.1331329	22.6660004	.460592419E-04	2.01954746
25.3640376	22.6660004	23.7226105	25.0220947
5.80524063	22.6660004	.383826991E-04	2.01949787
23.1331329	22.6660004	23.8453369	25.0465851
25.3640376	22.6660004	.460592419E-04	2.01954746
5.80463505	22.6660004	23.9442444	25.0955658
23.1331329	22.6660004	.460592419E-04	2.01969719
25.3843127	22.6660004	23.3696730	25.1200409
5.79898167	22.6660004	.537357846E-04	2.01979733
23.1576996	22.6660004	24.0171051	25.1445312
25.4382477	22.6660004	.153530855E-03	2.01979733
6.14340115	22.6660004	23.9434967	25.1690216
23.1331329	22.6660004	.239385050E-03	2.01979733
25.4627223	22.6660004		
5.90303707	22.6660004		
23.1576996	22.6660004		
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6.03213215	22.6660004		
23.1576996	22.6660004		
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23.1822815	22.6660004		
25.5605927	22.6660004		
5.96553571	22.6660004		
23.1576996	22.6660004		
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6.13941383	22.6660004		
23.1576996	22.6660004		
25.6095276	22.6660004		
6.09563923	22.6660004		
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25.6339874	22.6660004		
6.16622925	22.6660004		
23.1822815	22.6660004		
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23.1822815	22.6660004		
25.6584473	22.6660004		

FILE: BDAT82 DATA A

5.98545742		24.0907135	25.1934957
23.1822315	22.5364929	.468268991E-03	2.01984787
25.6584473	22.6660004		
5.96661949		24.0907135	25.2179718
23.1822315	22.9610748	.468268991E-03	2.01989746
25.7073609	22.7889709		
6.03079796		24.0661774	25.2424622
23.1622815	22.9610748	.452915905E-03	2.01974773
25.7318268	22.7397756		
6.03762150		24.0416412	25.2914124
23.1822315	22.9610748	.506651588E-03	2.01969719
25.7318268	22.7151947		
6.03848171		24.0416412	25.3153875
23.2068431	22.9856567	.498975161E-03	2.01974773
25.7807312	22.6660004		
6.04933548		24.1642914	25.3403625
23.2068431	22.9856567	.498975161E-03	2.01989746
25.8051910	22.6905975		
6.04210949		24.1883275	25.3648376
23.1822315	22.9856567	.498975161E-03	2.01934787
25.8296350	22.7397766		
6.03590012		24.0907135	25.4137873
23.2068431	22.9610748	.506651588E-03	2.01979733
25.8540955	22.7397766		
6.03251934		24.1397705	25.4382477
23.2068431	22.9856567	.506651588E-03	2.01984787
25.8785400	22.6905975		
6.03206253		24.1397705	25.4627208
23.2068431	23.0102386	.493975161E-03	2.01994705
25.9029446	22.6660004		
6.03034115		24.1642914	25.4871979
23.2068431	23.0102386	.491298502E-03	2.01999760
25.9274445	22.6905975		
6.02847004		24.1397705	25.5116577
23.2068431	23.0102386	.491298502E-03	2.01989746
25.9513390	22.6135529		
6.02696037		24.1883275	25.5361328
23.2314148	22.9856567	.498975161E-03	2.01979733
25.9765536	22.7397766		
6.02484417		24.3604589	25.5605927
23.2314148	23.0102386	.498975161E-03	2.01939746
26.0007782	22.7151947		
6.02514172		24.4585571	25.5850525
23.2314148	23.0102386	.483622076E-03	2.01949760
26.0252223	22.6660004		
6.02503681		24.4830647	25.6095276
23.2314148	22.7151947	.498975161E-03	2.01979760
26.0496674		24.5075836	25.6584473
6.02503681	23.0102386	.493975161E-03	2.02004719
23.2314148	22.7645738		
26.0741119		24.5320892	25.6584473
6.02538776	23.0102386	.498975161E-03	2.02009773
23.2314148	22.7151947		
26.0985565		24.5075836	25.6829071
6.02634430	23.0102386	.498975161E-03	2.02024746
23.2559967	22.7151947		
26.1229858		24.4585571	25.7073609
6.02719593	23.0348206	.493975161E-03	2.02039719
23.2559967	22.6905975		
26.1474304		24.4830627	25.7318268
6.02804750	23.0102386	.498975161E-03	2.02044773
23.2314148	22.7397766		
26.1713597		24.4340363	25.7562714
6.02698517	23.0348206	.498975161E-03	2.02039719
23.2314148	22.6135529		
26.1963045		24.5566101	25.7807312
6.02643108	23.0102386	.498975161E-03	2.02039719
23.2314148	22.7151947		
26.2207326		24.6540326	25.8296356
6.02622980	23.0348206	.498975161E-03	2.02059746
23.2314148	22.7151947		
26.2451732			

FILE: BDAT82 DATA A

6.02642155			
23.2314143	23.0102330	24.0546326	25.3296356
26.2451782	22.7643738	.491298502E-03	2.02049732
6.02551746			
23.2559967	23.0102386	24.7030438	25.8785400
26.2696075	22.7643738	.491298502E-03	2.02054787
6.02526283			
23.1085510	23.0102386	24.7036438	25.8785400
26.2940369	22.8135529	.498975161E-03	2.02049732
6.02450752			
23.2314148	23.0102386	24.7526550	25.9029840
26.3134662	22.7151947	.498975161E-03	2.02054787
6.02465847			
23.2314148	23.0102386	24.6546326	25.9029840
26.3428955	22.7151947	.506651588E-03	2.02039719
6.02218914			
23.2314148	23.0102386	24.7281494	25.9274445
26.3673243	22.7643738	.491298502E-03	2.02044773
6.01991367			
23.2314143	23.0102386	24.9261566	25.9703326
26.3673243	22.8135529	.491298502E-03	2.02054787
6.01839256			
23.2314148	22.9856567	24.7281494	26.0007782
26.3917542	22.7643738	.493975161E-03	2.02074713
6.01474476			
23.2068481	22.9856567	24.6791582	26.0252223
26.4101835	22.7151947	.493975161E-03	2.02074713
6.01333700			
23.2068481	22.9856567	24.7526550	26.0252228
26.4650269	22.7397766	.498975161E-03	2.02079773
6.01347923			
23.2314148	22.9856567	24.7771454	26.0436074
26.4650269	22.8135529	.491298502E-03	2.02074713
6.01231956			
23.2314148	22.9856567	24.3751373	26.0985565
26.4874582	22.8135529	.493975161E-03	2.02094746
6.01170234			
23.2314148	22.9856567	24.3996429	26.0985565
26.5138855	22.7397766	.493975161E-03	2.02084732
6.00999069			
23.2314148	22.9610748	24.3506470	26.1229853
26.5382790	22.7397766	.493975161E-03	2.02084732
6.00877752			
23.2314143	22.9610748	24.0506470	26.1474304
26.5627130	22.7151947	.491298502E-03	2.02059746
6.00753335			
23.2314148	22.9610748	24.9241333	26.1718597
26.5871429	22.8135529	.491298502E-03	2.02069759
6.00772572			
23.2314148	22.9610748	24.3261566	26.1963043
26.6115570	22.8331500	.498975161E-03	2.02079773
6.00802526			
23.2314148	22.9856567	24.3261566	26.2207336
26.6359711	22.7397766	.506651588E-03	2.02079773
6.00802325			
23.2559967	22.9856567	24.8751373	26.2207336
26.6603851	22.7151947	.491298502E-03	2.02079773
6.00822544			
23.2314143	22.9856567	25.0220947	26.2696075
26.6847992	22.7643738	.491298502E-03	2.02079773
6.00741573			
23.2314143	22.9610748	25.0710754	26.2696075
26.7032133	22.8135529	.493975161E-03	2.02079773
6.00721455			
23.2559967	22.9856567	25.0955658	26.2696075
26.7336273	22.8381500	.491298502E-03	2.02084732
6.00655400			
23.2559967	22.9856567	25.0955658	26.3134602
26.7530414	22.7397766	.493975161E-03	2.02094746
6.00644779			
23.2559967	22.9610748	25.0955658	26.3134662
26.7824554	22.7397766	.493975161E-03	2.02094746

FILE: BCAT32 DATA A

6.00624561		25.1200409	26.3073248
23.2314148	22.9850567	.491298502E-03	26.32114773
26.8068542	22.7151947		
6.00623417			
23.2559967	22.9856567	25.1690216	26.3917542
26.8068542	22.7643738	.493975161E-03	26.32109713
6.00588322			
23.2559967	22.9850567	25.1445312	26.3917542
26.8312683	22.3381500	.493975161E-03	26.32119732
6.00719070			
23.2559967	22.9856567	25.1445312	26.4161835
26.8312683	22.7397766	.493975161E-03	26.32124788
6.00673294			
23.2559967	22.9856567	25.1934967	26.4406128
26.8556671	22.7151947	.493975161E-03	26.32114773
6.00603199			
23.2559967	22.9856567	25.2609373	26.4650269
26.9044300	22.7869709	.491298502E-03	26.32119732
6.00618070			
23.2559967	22.9850567	25.3153875	26.4894562
26.9044300	22.8135529	.491298502E-03	26.32104759
6.00533000			
23.2559967	22.9856567	25.3403625	26.5133855
26.9552928	22.7869709	.493975161E-03	26.32124786
6.00592513			
23.2559967	22.9850567	25.3158875	26.5133855
26.9552928	22.7151947	.493975161E-03	26.32144713
6.00712585			
23.2559967	22.9850567	25.3158875	26.5332996
26.9020905	22.7151947	.491298502E-03	26.32134759
6.00657272			
23.2559967	22.9856567	25.3643376	26.5627136
26.9020905	22.7397766	.491298502E-03	26.32124786
6.00572300			
23.2559967	22.9856567	25.4137870	26.5871429
26.9020905	22.7397766	.491298502E-03	26.32129745
6.00560364			
23.2559967	22.9856567	25.4382477	26.6115570
26.9020905	22.7643738	.493975161E-03	26.32139759
6.00576401			
23.2805034	22.9856567	25.4627228	26.6353711
26.9020905	22.7397766	.491298502E-03	26.32134705
6.00541300			
23.2805034	22.9856567	25.4627228	26.6353711
26.9020905	22.7397766	.493975161E-03	26.32134705
6.00480043			
23.2805034	22.9856567	25.4627228	26.6603851
26.9020905	22.7397766	.493975161E-03	26.32149773
6.00480043			
23.2805034	22.9856567	25.5361526	26.6847992
26.9020905	22.7397766	.493975161E-03	26.32134732
6.00517040			
23.2805034	22.9856567	25.5605927	26.6847992
26.9020905	22.7397766	.491298502E-03	26.32169704
6.00534098			
23.2559967	22.9856567	25.5605927	26.7336273
26.9020905	22.7397766	.493975161E-03	26.32179718
6.00634773			
23.2805034	22.9856567	25.5850525	26.7336273
26.9020905	22.7397766	.493975161E-03	26.32169704
6.00604916			
23.2805034	22.9856567	25.6339674	26.7580414
26.9020905	22.7397766	.491298502E-03	26.32159786
6.00575161			
23.2805034	22.9856567	25.6584473	26.7824554
26.9020905	22.7397766	.475945417E-03	26.32169704
6.00534098			
23.2805034	22.9856567	25.6584473	26.8063542
26.9020905	22.7397766	.493975161E-03	26.32174759
6.00559044			
23.2805034	22.9856567	25.6829071	26.8312683
26.9020905	22.7397766	.475945417E-03	26.32174759

FILE: BDATA2 DATA A

6.00538326	23.0102336	25.6339874	26.8312683
23.2805634	22.6905975	.475945417E-03	2.02179713
27.2948151			
6.00594139	23.0348206	25.7318268	26.8558871
23.2805634	22.7645738	.483263991E-03	2.02169704
27.3191980			
6.00382301	22.9856567	25.7562714	26.8800812
23.2805634	22.6381500	.475945417E-03	2.02159786
27.3435822			
6.00231457			

FILE: BDATA34 DATA A

23.2970276	22.4118652	22.7070770	22.4856873
22.7038086	22.2642059	.0	.110000001E-04
- .110000004E-10			
23.2473943	22.4118652	22.7070770	22.4856873
22.9038036	22.1905534	.0	.110000001E-04
- .110000004E-10			
23.5917511	22.4118652	22.7316742	22.5843912
22.8300476	22.5594940	.405014277	2.02024555
5.32596538			
23.2970276	22.4364777	24.1562042	25.2098949
25.1609497	22.5340912	.519394696	2.02004523
5.30337048			
23.2970276	22.4364777	25.5525208	28.1152954
27.3843079	22.6578979	.692500710	2.02019596
5.77330289			
23.2970276	22.4364777	27.0428467	30.8340485
29.0154724	22.6578979	.919956625	2.02009583
5.72574043			
23.2724609	22.4364777	28.4317322	33.3976898
31.9005737	22.6578979	1.13267326	2.02004528
5.66176510			
23.2970276	22.4364777	29.6714172	35.6596832
33.6146098	22.6086884	1.40703297	2.02009582
5.60029221			
23.2970276	22.4364777	29.7928009	37.6731415
34.9387317	22.5840912	1.33185291	2.02039523
5.55445290			
23.2970276	22.4364777	30.6417339	39.4646149
36.0197754	22.6335008	2.35170341	2.02029514
5.51942921			
23.2970276	22.4364777	31.8103363	41.1076355
36.9069824	22.6824799	2.36337509	2.02034569
5.50441360			
23.2970276	22.4364777	32.4564362	42.6504094
37.8834277	22.5840912	3.83020973	2.02029514
5.51215647			
23.2970276	22.4364777	32.9151917	44.0716553
38.7009735	22.5840912	4.72928617	2.02044582
5.49660397			
23.3215942	22.4364777	33.5869812	45.1763977
39.3453674	22.5840912	5.40674114	2.02044582
5.47922302			
23.3215942	22.4610748	34.4335937	46.5255195
39.9413605	22.6824799	5.90218449	2.02044581
5.46602321			
23.3215942	22.4610748	35.4311138	47.7250366
40.5605011	22.6578979	6.40023699	2.02054596
5.45868773			
23.3215942	22.4610748	35.7557220	48.9921875
41.2502747	22.5840912	6.73076458	2.02039528
5.45323086			
23.3215942	22.4610748	36.3076732	50.4663732
42.0103912	22.5594940	7.05458736	2.02059555
5.45195293			
23.3215942	22.4656373	36.4275613	52.3333923
42.7634550	22.6335008	7.24151039	2.02049541
5.45451164			
23.3707275	22.4610748	35.1311138	54.2411041
43.5274658	22.6086884	7.30445862	2.02064514
5.46986961			
23.1937457	22.4610748	32.7703705	56.3058025
43.7168121	22.6086884	7.31651020	.2599994943E-04
.704600112E-08			
23.1741791	22.4610748	25.7971191	55.8177795
37.0936176	22.1657257	6.19420052	.2350000043E-04
.169200013E-08			
23.1937457	22.4610748	23.3401609	39.5361603
27.5305736	22.1657257	4.73765573	.230000005E-04
.101200004E-03			
23.0513000	22.4656373	22.2970276	25.2586654
25.1119690	22.2395732	4.40940475	.224977767E-04

.877500073E-09			
23.1004486	22.5348909	23.3215742	23.8372493
24.4994965	22.2395732	4.36135006	.219999929E-04
.748000106E-09			
23.1230305	22.5594940	23.3461609	23.6408691
24.1807404	22.2642059	4.34768531	.215000036E-04
.645000053E-09			
23.1004486	22.5594940	23.3461609	23.5917511
23.959437	22.2880184	4.33125732	.215000036E-04
.558999957E-09			
23.1004486	22.5594940	23.3215942	23.5671997
23.8372498	22.2149658	4.32104778	.215000036E-04
.494499997E-09			
23.0021362	22.5840912	23.1741791	23.4687789
23.8899719	22.2149658	4.31912899	.209999998E-04
.420000035E-09			
23.0267131	22.6086884	23.2233124	23.4444122
23.6654205	22.1657257	4.31774712	.204999960E-04
.368959942E-09			
23.0513000	22.6333008	23.2724609	23.3707275
23.6403691	22.1657257	4.31720924	.204999960E-04
.307500025E-09			
23.0758667	23.2970270	23.2724609	23.3707275
23.6163177	22.2888134	4.26186180	.204999960E-04
.286999979E-09			
22.9529724	23.3707275	23.0513000	23.3707275
23.5671997	22.2395782	4.25424122	.204999960E-04
.266499933E-09			
22.8546295	23.3707275	22.9038036	23.1741791
23.3707275	22.2642059	4.25525951	.195000030E-04
.233999931E-09			
22.7316742	23.2970276	22.3054504	23.0267131
23.2478943	22.2395732	4.25403118	.200000068E-04
.220000004E-09			
22.8054504	23.2233124	22.3792114	22.9775543
23.1250305	22.2642059	4.25234313	.195000030E-04
.195000002E-09			
22.8300476	23.1495972	22.9038036	22.9775543
23.1004486	22.2642059	4.25080770	.195000030E-04
.175500003E-09			
22.3548295	22.1250305	22.9038036	22.9775543
23.1250305	22.2642059	4.25057077	.189999992E-04
.151999996E-09			
22.8300476	23.0513000	22.9038036	22.9775543
23.1004486	22.2395782	4.24750014	.189999992E-04
.190000002E-09			
22.8548295	23.0267131	22.9283905	23.0021362
23.1250305	22.2642059	4.24719906	.189999992E-04
.190000002E-09			
22.8548295	22.9775543	22.9283905	23.0021362
23.1004486	22.2642059	4.24643230	.189999992E-04
.208999995E-09			
23.2478943	22.9775543	23.4935303	24.1562042
24.2052612	22.7316742	4.24412913	2.02004528
5.89710045			
22.9038036	22.9775543	25.0630035	27.4330750
26.6523437	22.6578979	4.24405193	2.01989555
5.89100742			
22.9038036	23.0021362	26.6035004	30.9324951
28.8452759	22.6824779	4.24412318	2.01974533
5.83745003			
22.9038036	23.0267131	27.0961029	34.0433704
30.8598323	22.6086884	4.24420547	2.01954596
5.77169037			
22.9283905	23.0267131	28.3939209	36.7392426
32.7703705	22.5594940	4.24453981	2.01949569
5.67879430			
22.9283905	23.0267131	28.7236786	38.9874573
34.3132324	22.5840912	4.24528027	2.01989555
5.62579441			
22.9283905	23.0267131	26.7938129	40.9867390
36.1157532	22.6086884	4.24765968	2.01999559

FILE: 2DAT84 DATA A

5.58850098			
22.8792114	23.0267131	27.7255554	42.6985337
37.1225739	22.6824799	4.36257744	2.02004523
5.55571270			
22.8792114	23.0267131	28.1639862	44.2603032
37.8405914	22.6086884	4.66664600	2.02009533
5.53362942			
22.9038036	23.0267131	28.8939209	45.5549940
38.4143219	22.5594940	4.94192600	2.01994514
5.51564503			
22.9038086	23.0267131	30.3506301	46.8080750
38.8919830	22.5594940	5.28291793	2.01994514
5.49807157			
22.9233905	23.0267131	30.6659851	47.9364319
39.1783752	22.6533003	5.60932446	2.01999569
5.48305798			
22.9233905	23.0513000	31.0051727	49.1562347
39.3692169	22.6533003	5.85850525	2.02009533
5.48231838			
22.9283905	23.0513000	31.2957306	50.7005920
39.5123138	22.5840912	6.01710224	2.02009533
5.48009682			
23.0513000	23.0758667	31.2473145	52.3333928
39.6533650	22.5348969	6.21592522	2.02024555
5.48353386			
22.9529724	23.0758667	31.0778198	54.0785522
39.9175415	22.6333003	6.35602188	2.02009533
5.48029900			
22.9529724	23.0513000	30.7386730	55.6177795
40.2748413	22.6333003	6.41666693	2.02014542
5.47841454			
22.9529724	23.0513000	30.7144470	57.6670380
40.4891052	22.6824799	6.46736763	2.02024555
5.47606550			
23.0267131	23.0021362	31.0051727	59.5102234
40.6313970	22.6333003	6.60842609	2.02024555
5.47525120			
22.9775543	23.1004486	30.3113708	61.4620361
40.7270613	22.5840912	6.71497726	2.02019596
5.46804523			
22.9775543	23.6654205	31.4651489	63.4985046
40.3224640	22.6533003	6.38201809	2.02019596
5.46603094			
23.0021362	23.4444122	32.0214539	65.6414642
40.9649506	22.6533003	7.00630138	2.02024555
5.47040272			
23.0021362	23.3952942	32.1423137	67.9124146
41.8204478	22.2888134	7.15883446	2.95000063E-04
40.7100131E-08			
22.9038036	23.3215942	29.8170776	67.3444214
40.4653015	22.1905534	7.15898300	2.75000057E-04
2.69500000E-03			
22.7562714	23.3215942	28.1152954	68.6872253
38.3426351	22.1657257	6.98196697	2.70000019E-04
5.140400003E-08			
22.7070770	23.3215942	23.1987457	62.3324230
30.0112305	22.1903534	5.43112679	2.59999943E-04
5.132599903E-08			
22.6578979	23.3215942	22.8792114	32.5771942
24.9405518	22.1905534	4.43838070	2.550000050E-04
5.739500017E-09			
22.7808685	23.2970276	23.0021362	25.1609497
23.8617359	22.2149653	4.39904113	2.50000012E-04
5.725000060E-09			
22.7316742	23.2970276	23.0021362	23.9103734
23.6163177	22.2149653	4.27900543	2.44999974E-04
5.661499966E-09			
22.7562714	23.2724609	22.9775543	23.5917511
23.5426483	22.2149653	4.37809835	2.39999936E-04
5.623999963E-09			
22.7562714	23.2724609	23.0021362	23.4639789
23.4444122	22.2149653	4.35820193	2.30000005E-04

FILE: BDAT34 DATA A

.552000001E-09	22.2478943	22.9775543	23.3952942
22.7582714	22.1903534	4.35490131	.224999967E-04
23.4198450			
.517500043E-09	23.1987457	23.0021362	23.3952942
22.7808685	22.2642059	4.35375023	.219999929E-04
23.4198450			
.505999909E-09	23.2724009	23.0021362	23.6163177
22.7808685	22.2642059	4.35321236	.215000036E-04
23.4444122			
.451499949E-09	23.2478943	23.0753667	23.6163177
22.7808685	22.1657257	4.35305882	.209999988E-04
23.4444122			
.440999903E-09	23.1004436	23.0758067	23.6163177
22.8792114	22.2642059	4.35393006	.204999960E-04
23.4689789			
.450999904E-09	23.0758067	23.0513000	24.0580902
22.7808685	22.7070770	4.33471203	2.0202810
23.3461609			
6.49422109	23.1004480	24.3033600	26.0415107
22.8300476	22.7316742	4.35540249	2.02039528
25.6740352			
6.36887455	23.1250305	25.7726746	29.4042816
22.8300476	22.6578979	4.33540249	2.02044582
28.0422363			
6.27447510	23.1250305	26.8476257	32.5771942
22.8300476	22.5840912	4.33532619	2.02064514
30.2780762			
5.80974197	23.1250305	27.6524506	35.4134940
22.8546295	22.0080884	4.33517265	2.02089596
32.1906530			
5.74639797	23.1004486	28.1390532	37.9405914
22.8546295	22.6335003	4.33455849	2.02099514
33.8074046			
5.08787193	23.1004486	28.4804077	39.9175415
22.8792114	22.6578979	4.33432865	2.02104563
35.4915019			
5.64051723	23.1495972	28.3830719	41.7492065
22.8546295	22.6578979	4.35670307	2.02099514
36.7392426			
5.59894733	23.1741771	28.4500699	43.2670135
22.8792114	22.5840912	4.52532101	2.02114582
37.8405914			
5.50217534	23.1741791	28.3830719	44.9223323
22.9038066	22.5840912	4.93386650	2.02124596
38.6532135			
5.53455659	23.1495972	23.2126770	46.3843384
22.8792114	22.6578979	5.27032852	2.02119541
39.2976685			
5.51299477	23.1495972	29.4285736	47.0730548
22.8792114	22.6578979	5.04079857	2.02119541
39.8222198			
5.49642080	23.1495972	30.1082764	48.8515320
22.9038066	22.6824799	5.73596210	2.02119541
40.0843048			
5.50895214	23.1495972	31.0293984	50.2096710
22.8792114	22.6335003	5.34315205	2.02124596
40.1557617			
5.49615283	23.1495972	31.6587219	51.5870290
22.8792114	22.5594940	5.97921003	2.02134514
40.2748413			
5.48571110	23.1250305	31.1504669	53.1487427
22.8792114	22.5340912	6.17347336	2.02124596
40.4653015			
5.47674047	23.1250305	30.7671399	54.7743871
22.8792114	22.7070770	6.34657955	2.02124555
40.7270313			
5.47102261	23.1004436	30.5690303	56.5813293
22.8792114	22.7070770	6.48091888	2.02134514
41.0363007			
5.46671104	23.0758067	30.6659851	58.0354523
22.8792114	22.6086034	6.04742374	2.02124596
41.4403992			

FILE: BDATA4 DATA A

5.46421719	23.0513000	31.0051727	60.9575045
22.8792114	22.6086834	6.73122520	2.02119541
41.8679352			
5.46403176	23.0267131	31.1262512	63.4071350
22.8792114	22.5594940	6.36106110	2.02114582
42.3683177			
5.46435070	22.9775543	31.2230933	65.8917236
22.9033086	22.6086834	6.72677307	2.02129555
42.7951519			
5.51064014			

FILE: LBDT84B DATA A

1	-.590658632138416854E-02		
2	-.103085815003384031		
3			
.999999975E-05	.999999975E-05	-.590766594E-02	.999999975E-05
2.07499981	-.242019951	-.230184615	.214959502
4.14999962	-.446545039	-.454462647	.361443400

FILE: 3DAT85 DATA 4

21.9608307	19.8138733	22.4285736	22.3301392
21.9854534	22.2565019	.0001	.145000004E-04
-1.145000002E-10			
21.9608307	19.8138733	22.4285736	22.3547516
21.9854534	22.2565019	.0001	.145000004E-04
-1.145000002E-10			
21.9608307	19.8138733	22.5023956	22.4039612
21.7144928	22.6494939	.230296209E-03	2.02093029
5.83333683			
21.9608307	19.7391388	24.1973377	24.2219233
24.2219238	22.6745911	.767653983E-04	2.02073097
5.79254723			
21.9115753	19.7891388	26.3758698	26.9130096
27.0350189	22.6745911	.230296209E-03	2.02063043
5.74168491			
21.9115753	19.7891388	28.3995972	29.8092957
29.8150665	22.6253967	.158750832	2.02073097
5.0555142			
21.9362030	19.7391388	30.0277100	31.5785691
32.1345673	22.5762024	.707393169	2.02073097
5.58481075			
21.9362030	19.7891388	31.7477112	33.9442902
33.9442902	22.6745911	1.346666939	2.02033015
5.50324917			
21.9362030	19.7891388	32.3520508	34.9070292
35.3637238	22.6494939	2.03103371	2.02033015
5.46040726			
21.9115753	19.7391388	33.3399384	36.3719330
36.8992920	22.6494939	3.03983307	2.02033015
5.42847324			
21.9115753	19.7644196	34.0888062	37.4281475
38.6455383	22.5762024	3.34305668	2.02033015
5.40624905			
21.9115753	19.7644196	35.0512348	38.4783325
40.0051830	22.6253967	4.23355481	2.02033015
5.39088390			
21.8869476	19.7396351	35.2195435	39.0752716
40.6242676	22.6253967	4.74709606	2.02033015
5.38199902			
21.8869476	19.7396351	36.2230121	40.0523412
41.3852330	22.5762024	5.34816433	2.02033015
5.37371349			
21.8376770	19.7149506	37.2106781	41.2901764
42.4298706	22.6253967	5.35535567	2.02033015
5.36697573			
21.8623047	19.7149506	38.5022273	42.9514465
43.4438525	22.7237854	6.24832754	2.02033015
5.36212540			
21.8376770	19.6902161	38.3365734	44.3875231
44.3804713	22.6494939	6.41904640	2.02098083
5.35855100			
21.8376770	19.6902161	39.4331207	47.6473184
45.4811554	22.6007996	6.61786842	2.02103043
5.35464131			
21.8130493	19.6654968	39.0622284	50.1086121
46.2334534	22.5762024	6.75372337	2.02103043
5.35403538			
21.8130493	19.6902161	40.8383942	52.7689056
47.0357819	22.6253967	6.90497112	2.02093029
5.30352097			
21.7834064	19.6654968	42.0502319	55.9029541
47.6473184	22.3301392	6.94795990	.250000012E-04
.300000003E-03			
21.7391357	19.6902161	42.3349915	56.8975372
46.5180664	22.2070616	6.94872761	.244999974E-04
.218050000E-03			
21.7637634	19.6902161	40.3621326	56.5276642
45.5755005	22.2318095	6.94872761	.235000043E-04
.109200010E-03			
21.7637634	19.7149506	40.3359711	55.7640331
44.3713983	22.3055267	6.94872761	.235000043E-04

FILE: BDATA5 DATA A

.140999939E-08	19.6902161	40.9097595	54.7674408
21.7637634	22.2309143	6.94872761	.230000005E-04
42.5958862			
.115000010E-08	19.6902161	40.0523412	54.5265223
21.7637634	22.2316895	6.94872761	.230000005E-04
40.8146057			
.988999993E-09	19.7149506	39.2661438	53.6523625
21.7637634	22.2070613	6.94872761	.224999967E-04
39.5235034			
.810000067E-09	19.7149506	37.8807526	52.9551239
21.7637634	22.2809143	6.94872761	.219997929E-04
38.3588713			
.703999769E-09	19.7149506	36.0840607	52.0001221
21.7637634	22.3301392	6.94872761	.224999967E-04
37.133245			
.562500047E-09	19.7149506	34.5943146	50.3892365
21.7637634	22.2809143	6.95103073	.219999929E-04
36.2280121			
.483999951E-09	19.7149506	34.7386627	49.0549774
21.7637634	22.2070613	6.95025302	.219999929E-04
35.4838409			
.418000079E-09	19.7149506	34.7386627	47.9094108
21.7637634	22.2070613	6.93414211	.215000006E-04
34.7867737			
.343999940E-09	19.7149506	34.0406342	47.3649902
21.7391357	22.2503019	6.89192104	.219999929E-04
33.7997234			
.285999890E-09	19.7149506	33.4381714	46.4945221
21.7391357	22.3301392	6.84816456	.219999929E-04
32.9798431			
.241999976E-09	19.7149506	32.9557190	45.8820038
21.7637634	22.3055267	6.80364132	.215000003E-04
32.3762054			
.193499994E-09	19.6902161	32.2070613	44.9855804
21.7637634	22.2316895	6.75834942	.219999929E-04
31.6993256			
.131599994E-09	19.7149506	31.0605304	44.0404053
21.7637634	22.2316895	6.68849277	.215000003E-04
31.0458374			
.107499995E-09	19.7149506	30.7551270	43.0935974
21.7391357	22.2309143	6.63015079	.209999998E-04
30.4642722			
.840000014E-10	19.7396851	30.3672943	42.4535980
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45.2059174	45.0643005	45.4654541	45.7484436
46.4788513	48.8752899	-.307061709E-03	1.28037234
2.31587315	2.56633720		
45.2531128	45.0640952	45.4890442	45.7012939
46.5023950	48.8877136	-.307061709E-03	1.28077221
2.31415558	2.96590533		
45.2531128	45.0643005	45.5126343	45.7484436
46.5259399	47.7488403	-.307061709E-03	1.28067207
2.31320572	2.96245766		
45.2531128	45.06379059	45.5362244	45.7720337
46.5023956	47.1377258	-.307061709E-03	1.28072156
2.31273419	2.96203232		
45.2707181	45.0643005	45.5362244	45.7720337
46.4788513	47.5138855	-.230296209E-03	1.28072160
2.31175995	2.96072102		
45.3003032	45.0643005	45.5597992	45.7956085
46.5023950	48.4531403	-.153530311E-03	1.28047130
2.31271043	2.96106761		
45.3239136	45.0643005	45.5597992	45.9191833
46.5023950	48.6408081	-.787653983E-04	1.28087234
2.31305504	2.96272755		
45.3475037	45.06379059	45.5833893	45.8603177
46.5023950	47.7132553	-.153530311E-03	1.23062153
2.31209037	2.96091270		
45.3475037	45.1115112	45.5833893	45.8893926
46.5259399	47.2552948	.0	1.28047180
2.31105232	2.95923710		
45.3475037	45.1351160	45.5833893	45.8663177
46.5494090	47.8664372	.0	1.28072166
2.31099129	2.95973587		
45.3475037	45.1587219	45.6009794	45.8663177
46.5965576	48.8513524	.0	1.28077221
2.31120908	2.96013260		
45.3475037	45.1587219	45.6069794	45.8663177
46.5965576	48.8513524	.0	1.23037234
2.31087780	2.95939900		
45.3475037	45.2059174	45.6069794	45.8663177
46.6436310	47.6783000	.0	1.28047130
2.30904375	2.95743275		
45.3475037	45.2059174	45.6009794	45.8603177
46.6436310	47.68071092	.0	1.28067207
2.31000423	2.95335781		
45.3710937	45.2059174	45.6069794	45.8603177
46.6201019	47.6878790	.0	1.28072160
2.30983824	2.95823958		
45.3946838	45.2059174	45.6305542	45.8893926
46.6201019	48.7111664	.0	1.28062153
2.30978534	2.95790103		
45.3946838	45.2059174	45.6305542	45.9134074
46.6671753	48.9221302	.0	1.28052235
2.30909348	2.95684523		
45.3946838	45.2059174	45.6305542	45.9370270
46.6436310	47.7018585	.0	1.28062153
2.30965805	2.95779705		
45.4132734	45.2059174	45.6541290	45.8893926
46.6436310	48.9905973	.0	1.28047130
2.31143605	2.95572919		
45.4132739	45.2295227	45.6541290	45.9134674
46.6436310	47.3720435	.0	1.28057194
2.31097698	2.95937157		
45.4132739	45.2295227	45.6777191	45.9841614
46.6436310	48.0403031	.0	1.28067207
2.31115723	2.95938410		
45.4182739	45.2531128	45.6777191	45.9606013
46.6436310	48.6408081	.0	1.28042221
2.30993740	2.95769501		
45.4182739	45.2295227	45.6777191	45.9841614
46.6907176	47.4608732	.0	1.28067207

FILE: BDAT138 DATA A

2.31115723	2.35983410		
45.3946833	45.2295227	45.6777191	45.9606018
46.6671753	46.8789673	.0	1.28092194
2.31100831	2.96098900		
45.3946838	45.2295227	45.6777191	45.9370270
46.6907196	47.2843811	.0	1.28077221
2.31146526	2.96045971		
45.3946838	45.2295227	45.6541290	45.9606013
46.7142487	49.1331177	.0	1.28067207
2.31435871	2.96393394		
45.3710437	45.2295227	45.6541290	45.9370270
46.7377777	46.5235291	.0	1.28107166
2.31456947	2.96512990		
45.3475037	45.2295227	45.6541290	45.9370270
46.6430310	47.2552948	.0	1.28062153
2.31350040	2.96271301		
45.3710937	45.2531120	45.6541290	45.9134674
46.7142487	47.3023224	.0	1.28057194
2.31323201	2.96232319		
45.3475037	45.2295227	45.6305542	45.9370270
46.7142487	48.8752399	.0	1.28062153
2.31311607	2.96222591		
45.3710937	45.2295227	45.6305542	45.9134674
46.7377777	49.2571191	.0	1.28077221
2.31351471	2.96308517		
45.3710937	45.2531123	45.6305542	45.9134674
46.7142487	48.9062195	.0	1.28067207
2.31346226	2.96278572		
45.3946838	45.2531123	45.6305542	45.9370270
46.7377777	47.1377253	.0	1.28037167
2.31215191	2.960941298		
45.4182739	45.2531123	45.6541290	45.9370270
46.7142487	47.9602003	.0	1.28042221
2.31244809	2.96097374		
45.4182739	45.2295227	45.6777191	45.9370270
46.6907196	48.7815094	.0	1.28052225
2.31216717	2.96078110		
45.4182739	45.2531123	45.6777191	45.9370270
46.7142487	49.2039143	.0	1.28067130
2.31169224	2.96005030		
45.4654541	45.2295227	45.7012939	45.9606013
46.7377777	47.8078796	.0	1.28062153
2.31234741	2.96124172		
45.4090442	45.2531123	45.7012939	45.9370270
46.7377777	47.9608820	.0	1.28057194
2.31200123	2.96068382		
45.4890442	45.2531123	45.7248638	46.0077362
46.7377777	48.7346191	.0	1.28072156
2.31227207	2.96137619		
45.5126345	45.2295227	45.7248638	46.0077362
46.7377777	49.4376073	.0	1.28072156
2.31175925	2.96072102		
45.5126343	45.3003082	45.7720337	46.0077362
46.8033801	48.4296875	.0	1.28057194
2.31200123	2.96068382		
45.5362244	45.3003082	45.7720337	46.0548553
46.8319092	47.6513782	- .76765393E-04	1.28062153
2.31221962	2.96107769		
45.5597992	45.3247136	45.8191833	46.0543553
46.8033801	47.7488403	.0	1.28062153
2.31157875	2.96025058		
45.5833893	45.3003082	45.8427429	46.0784302
46.7613220	48.4296875	.0	1.28032180
2.31245232	2.96183372		
45.6009774	45.3235136	45.8427429	46.0784302
46.8083801	48.8677130	- .76765393E-04	1.28067207
2.31106935	2.96049023		
45.6069794	45.3235136	45.8663177	46.1255493
46.8789673	47.8078796	.0	1.28097153
2.31240602	2.96220303		
45.6009774	45.3235136	45.8663177	46.0784302
46.8554382	48.9260254	- .76765393E-04	1.28077221

FILE: BDATA33 DATA A

2.31172130	2.96373873		
45.6069794	45.2710937		
46.8789673	47.6193207	45.3898926	46.1255493
2.31175995	2.96072102	-.767653983E-04	1.28072166
45.6069794	45.4182739		
46.9024963	48.5000610	45.3663177	46.1491089
2.31155586	2.96069050	-.767653983E-04	1.28032130
45.5833893	45.4182739		
46.9260254	48.9221802	45.3663177	46.1726685
2.31151772	2.96075821	-.767653983E-04	1.28037234
45.5833893	45.4418040		
46.9024963	48.0770215	45.3893926	46.1726685
2.31082335	2.95904050	.0	1.28077221
45.5833893	45.4654541		
46.9260254	47.3726485	45.3427429	46.1255493
2.31090064	2.95950503	.0	1.28067207
45.5833893	45.4654541		
46.9495544	48.1011047	45.3427429	46.1726685
2.31047716	2.95900070	.0	1.28072166
45.5597992	45.4654541		
46.9260254	48.5939025	45.3427429	46.1491089
2.31334377	2.96258695	-.767653983E-04	1.28082130
45.5597992	45.4654541		
46.8789673	48.8043022	45.3663177	46.1255493
2.31371021	2.96391296	-.767653983E-04	1.28102207
45.5597992	45.4654541		
46.9260254	48.1480560	45.3427429	46.1255493
2.31233605	2.96233082	-.767653983E-04	1.28067207
45.5597992	45.4390442		
46.9495544	47.0201263	45.3427429	46.1255493
2.31227207	2.96137619	-.153530811E-03	1.28072166
45.5597992	45.4654541		
46.9495544	47.4198003	45.3427429	46.1726685
2.31386049	2.96364307	-.767653983E-04	1.28062180
45.5597992	45.4654541		
46.9495544	48.3468081	45.3191333	46.1255493
2.31334377	2.96227782	.0	1.28067207
45.5362244	45.4418040		
46.9260254	48.2283997	45.3427429	46.1013397
2.31430803	2.96420479	.0	1.28097234
45.5597992	45.4418040		
46.9260254	48.0393829	45.3427429	46.1255493
2.31438828	2.96466541	.0	1.28097153
45.5362244	45.4182739		
46.9024963	48.1950073	45.3191333	46.1013397
2.31398904	2.96380806	.0	1.28082130
45.5362244	45.4182739		
46.9024963	47.3343811	45.3191333	46.1013397
2.32816387	2.96208018	.0	1.28087234
45.5597992	45.4182739		
46.8789673	47.5567371	45.3427429	46.1013397
2.46695137	3.15960217	.767653983E-04	1.28077221
45.5833893	45.4182739		
46.9024963	48.5456177	45.3427429	46.1013397
2.63842373	3.37526512	.767653983E-04	1.27927203
45.5833893	45.4418040		
46.9024963	49.3205414	45.3427429	46.1255493
2.53320789	3.24484062	.767653983E-04	1.28092194
45.6069794	45.4182739		
46.9495544	48.3592834	45.3663177	46.1013397
2.50646210	3.21785009	-.767653983E-04	1.28382206
45.6069794	45.4654541		
46.9260254	47.5603826	45.3898926	46.1255493
2.39105388	3.06264210	-.767653983E-04	1.28037234
45.6069794	45.4418040		
46.9024963	47.7723339	45.3898926	46.1255493
2.28531142	2.962771626	-.767653983E-04	1.28032130
45.6069794	45.4654541		
46.9024963	48.5235291	45.3134674	46.1491089
2.28322607	2.92372227	.0	1.28052235
45.6541290	45.4418040		
46.9495544	49.2971191	45.3134674	46.1726685
		-.767653983E-04	1.28062153

FILE: BCDAT133 DATA A

2.28537042	2.92630959		
45.6777191	45.4890442	45.9606018	40.1962280
46.9730335	47.8897705	.767653983E-04	1.28067207
2.28362274	2.92457104		
45.7248638	45.4890442	45.9841614	46.2433319
46.9730835	47.2317810	.767653933E-04	1.23062153
2.28302097	2.92366537		
45.7248688	45.5362244	45.9841614	46.2433319
46.9965973	47.5136855	.767653933E-04	1.30467156
2.36278915	3.08313560		

FILE: BDATA191 DATA A

25.4627533	25.4609673	25.4627533	25.5606232
25.5116832	22.7393224	.0	-.1499999607-05
.150000012E-10	25.4609673	25.4627533	25.5606232
25.4133134	24.3359985	-.230296209E-03	-.1499999607-05
25.5116832	25.2669678	25.4627533	25.5606232
.150000012E-10	24.4095612	-.307061709E-03	25.5850983
26.1230316	25.4609678	25.4627533	2.02085400
25.9733041	24.4095612	26.7580719	27.5630341
6.13977432	25.4159180	.767653983E-04	2.02095413
25.4627533	22.6168365	28.2937522	30.0677948
28.1963959	25.4159180	.307061709E-03	2.02145386
6.10774326	22.7152252	29.5309052	32.7542114
25.4872234	25.2914429	.472107232E-01	2.02145386
30.5043335	24.4585876	31.0373993	35.6195984
6.04719543	25.2669678	.405244589	2.02120399
25.4872234	23.9189911	32.7300720	38.0159149
32.6334839	25.2914429	.865146101	2.02125359
5.93803692	22.4933354	34.5378265	40.2350922
25.4872234	25.2914429	1.40963261	2.02155372
34.9707947	24.6301575	36.1237030	42.5639191
5.84574440	25.2669678	3.03062153	2.02125359
25.4872234	23.9189911	37.6810608	44.7887674
36.7232056	25.2914429	4.04108353	2.02115440
5.78322792	24.3359985	39.1362793	48.1555176
25.4872234	25.2669678	4.98391724	2.02150440
38.5655823	23.0343511	40.7111664	50.3017883
5.74611950	25.2914429	5.35847065	2.02120399
25.4872234	24.6301575	42.2080994	53.5052948
40.4017639	25.2669678	5.69092555	2.02120413
5.71814346	23.9189911	43.6536407	56.4964905
25.4627533	25.2914429	5.89205170	2.02155399
42.8247070	24.3359985	45.1662140	59.7707977
5.70330811	25.2669678	6.07321835	2.02110306
25.4627533	23.0343511	46.6275787	62.9570263
46.2538240	25.2914429	6.22060776	2.02190399
5.69600773	24.6301575	48.1320343	66.4675751
25.4627533	25.2669678	6.36492634	2.02165413
47.9676810	23.9189911	49.7260742	69.7527771
5.69435406	25.2914429	6.45474243	2.02140427
25.4627533	24.3359985	51.2921906	72.7496043
49.3982544	25.2669678	6.54609299	2.02115440
5.69603713	23.0343511	52.7375336	75.7534332
25.4627533	25.2914429	6.65663523	2.02160358
50.2875824	24.6301575	54.2487946	78.7145232
5.70100021	25.2669678	6.76180363	2.02150415
25.4872234	23.9189911	55.8948975	81.4935455
51.1988220	25.2914429	6.82705402	2.02195358
5.70074399	24.3359985	57.055131	34.1223297
25.4872234	25.2669678	6.87771988	2.02140427
52.2949982	23.0343511		
5.70967102	25.2914429		
25.4872234	24.6301575		
55.4620404	25.2669678		
5.71502972	23.9189911		
25.4872234	25.2914429		
54.5273457	24.3359985		
5.71856735	25.2669678		
25.4872234	23.0343511		
55.3948975	25.2914429		
5.72190285	24.6301575		
25.4872234	25.2669678		
57.0512390	23.9189911		
5.72843361	25.2914429		
25.5116832	24.3359985		
53.4337147	25.2669678		
5.73031684	23.0343511		
25.4872234	25.2914429		
59.1260632	24.6301575		
5.73852348	25.2669678		
25.5116832	23.9189911		
60.8044759	25.2914429		

FILE: BDATA01 DATA A

5.74444199			
25.5116882	25.3403931	58.6661224	86.6756293
62.3628845	24.4340668	6.93375874	2.02215385
5.75142670			
25.5116882	25.3159130	60.0006714	89.0829315
63.8942103	22.9119415	6.99900913	2.02195353
5.75092368			
25.5116882	25.3393433	61.1715393	91.3954773
65.4669342	22.7890015	7.00207996	2.02130386
5.76235952			
25.5116882	25.3648882	62.2942352	93.4605255
66.8337140	24.3359935	7.04276562	2.02193353
5.76642704			
25.5361633	25.2669678	63.3004608	95.6915436
68.1918335	24.4831035	7.07730961	2.02175426
5.76949596			
25.5361633	25.3403931	64.2364807	97.8713226
69.4816132	22.5184326	7.08114815	2.02200413
5.77465725			
25.5361633	25.3403931	65.1026306	99.5064697
70.6557405	24.1152649	7.14563084	2.02240372
5.78348446			
25.5361633	25.2180176	65.7447327	101.372955
71.8274039	23.9435272	7.14563084	2.02255440
5.78917217			
25.5361633	25.2914429	66.7855988	103.703506
72.9274231	23.0840149	7.19859836	2.02235413
5.79102707			
25.5361633	25.3403931	67.6025391	106.131663
73.9620209	22.7398424	7.20013426	2.02290440
5.79604053			
25.5361633	25.3893433	68.3730316	108.190353
74.9703674	23.7226410	7.22700214	2.02255440
5.81708336			
25.5361633	25.3403931	69.1198573	109.925401
75.7704745	24.4535876	7.22700214	2.02250399
5.81904733			
25.5361633	25.2669678	69.8431350	111.529383
76.9149170	24.0907440	7.22853750	2.02283335
5.82261031			
25.5361633	25.2669678	70.5203857	113.024155
77.8057700	22.3381005	7.23007293	2.02305412
5.82701874			
25.5600232	25.3403931	71.1517639	114.473480
78.5172071	22.3135436	7.29609108	2.02305412
5.83025551			
25.5600232	25.3159130	71.7824554	115.314380
79.2976074	24.5560400	7.29609103	2.02245426
5.832594175			
25.5600232	25.3648882	72.3674774	117.049011
80.0746701	22.7598224	7.29762650	2.02275372
5.83424500			
25.5600232	25.4627533	72.7294281	119.239075
80.7403107	23.9435272	7.29685379	2.02295399
5.83947563			
25.5600232	25.4133134	73.4459534	119.322361
81.4271240	23.5202146	7.29762650	2.02240372
5.83930302			
25.5653983	25.4382935	73.7395305	120.384064
82.0467854	22.7598224	7.29916191	2.02235413
5.84219265			
25.5600232	25.4627533	74.3655701	121.319000
82.6215973	24.5076141	7.29839420	2.02265333
5.85519505			
25.5600232	25.4382935	74.4776154	121.337767
81.3914573	22.9850673	7.30146503	.219999929E-04
23.09999947E-08			
25.5600232	26.0741425	72.0975342	113.906235
80.0526300	21.6044739	7.00223274	.209999998E-04
1.93149939E-08			
25.4382935	25.6584773	67.7652405	113.465607
77.3610077	22.4856873	7.30223274	.204999990E-04

FILE: SDAT191 DATA A

.15785000E-03	25.5361633	62.9118958	108.613998
25.4138134	25.1935272	7.30146503	.204999960E-04
73.8722992			
.14965000E-08		52.0619507	103.020203
25.1445613	25.4872284	7.30146503	.195000030E-04
70.8812581	22.4446259		
.13259999E-08		49.1639862	97.9144135
24.8016315	25.0955963	7.30223274	.139999992E-04
68.0105743	23.2063787		
.11779999E-08		46.2743835	94.1978760
24.6056517	24.8506775	7.30146503	.134999953E-04
65.2848206	25.2669678		
.10915000E-08		42.9668834	91.2430267
24.4340600	24.9241638	7.29146483	.130000006E-04
62.2713318	21.9276423		
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.132000011E-C8			
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27.3338776	25.1592712	32.6233556	36.6417389
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26.2110138			
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.999999975E-05      .999999975E-05      .121141593E-01      .999999975E-05
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39.4249878      -.151704512E-01      -.161511033E-01      .140809476E-01
41.4999847      -.161919236E-01      -.170650065E-01      .149490178E-01
43.5749817      -.175781906E-01      -.179788291E-01      .161199152E-01
45.6499939      -.179156899E-01      -.183926513E-01      .164025566E-01
47.7249908      -.198418677E-01      -.193064744E-01      .179973662E-01
49.7999873      -.212051451E-01      -.207202371E-01      .191076934E-01
51.8749847      -.221323259E-01      -.216341133E-01      .198546469E-01
53.9499817      -.234640593E-01      -.225479364E-01      .209145010E-01
56.0249939      -.243223674E-01      -.234617651E-01      .215907372E-01
58.0999908      -.253710866E-01      -.243755817E-01      .224083360E-01
60.1749878      -.261415780E-01      -.253894044E-01      .230059299E-01
62.2499347      -.268916368E-01      -.262032270E-01      .235792315E-01
64.3249817      -.275810735E-01      -.271170437E-01      .240435955E-01
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68.4749908      -.291356146E-01      -.289440950E-01      .252575076E-01
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72.6249847      -.314725876E-01      -.307723343E-01      .270011067E-01
74.6999817      -.320566749E-01      -.316861570E-01      .274555323E-01
76.7749786      -.328083999E-01      -.325999737E-01      .279701114E-01
78.8499908      -.336790518E-01      -.335138023E-01      .287372470E-01
80.9249878      -.346331716E-01      -.344276249E-01      .292722225E-01
82.9999847      -.351826217E-01      -.353414416E-01      .298455993E-01
85.0749817      -.361285210E-01      -.362552645E-01      .303219825E-01
87.1499786      -.371408841E-01      -.371690310E-01      .312303778E-01
89.2249908      -.384439945E-01      -.380329090E-01      .319168150E-01
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93.3749847      -.405226248E-01      -.399105489E-01      .329161167E-01
95.4499817      -.4052263126E-01      -.403243716E-01      .333198726E-01
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103.749985      -.437500724E-01      -.444796622E-01      .354395366E-01
105.824982      -.455071522E-01      -.453934789E-01      .366104722E-01
107.899979      -.470253841E-01      -.463075015E-01      .380013517E-01
109.974976      -.484952629E-01      -.472211242E-01      .394275703E-01
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